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# NEW DETERMINATIONS OF THE COEFFICIENTS OF FRICTION OF LUBRICATED JOURNALS, AND ON THE LAWS GOVERNING SUCH FRICTION.[1]

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The writer became convinced, many years ago, that the generally accepted values of the coefficient of friction for lubricated surfaces were not applicable to such heavy machinery as he had been called upon, in the course of professional work, to design, to construct, and to operate. Experience frequently seemed to indicate, also, a wide departure, in such cases, from the accepted "laws of friction."

In the year 1869, or earlier, he invented an apparatus to re-determine these laws and these coefficients for a wide range of temperatures, pressures and velocities. The construction of the machine was delayed, however, some time, and no experiments were made for sev-

[1] A paper read at the October meeting of the Am. Inst. Mining Engineers.

eral years, when, finally, the construction of the apparatus was commenced in the workshops of the Stevens Institute of Technology, and experiments were begun in the Mechanical Laboratory organized by the writer in connection with the Department of Engineering.

These machines have now been in use about five years, and have furnished an immense amount of valuable information. Those now in use are of two styles: one designed and built by the Class of 1877, Figs. 1 and 2; the other a much larger machine, Figs. 3 and 4. The first has been already frequently described,[1] and a working drawing of the second has been also published.[2] For convenience, engravings of both are herewith reproduced.

Fig. 1.

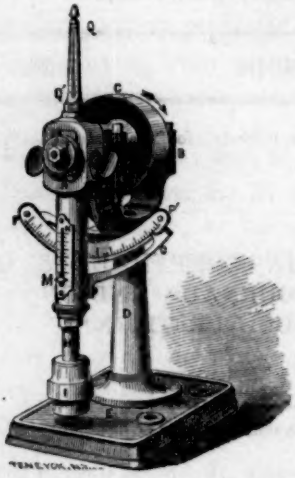
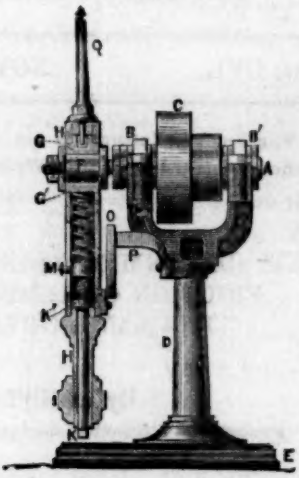


Fig. 2.



In the "'77 machine," a journal, *F*, is made on the overhung extremity of a shaft carried in the two bearings, *B B'*. This journal is grasped by brass boxes which are carried in a pendulum, *H H*. They are forced against the journal by a screw which compresses a coiled spring with a pressure which is read off on the scale, *N M*. A weight at the lower end of the arm, at *I*, gives it the necessary resistance to deflection. The angle of deflection is measured on the arc, *P P'*, in pounds of frictional resistance at the surface of the journal, *i. e.*, in such units that the division of the figures indicated

[1] In *Scientific American*, *R. R. Gazette*, Jour. Frank. Inst., "Johnson's Cyclopedia," "Knight's Mechanical Dictionary," etc.

[2] *R. R. Gazette*, Jan. 18th, 1878, p. 25.

by the pointer, at any given angle of deflection, by the figure indicated by the other pointer on *N M*, which indicates the total pressure on the journal, gives the coefficient of friction. A thermometer, *Q*, gives the rise of temperature as the bearing warms up.

The machine is fitted for a wide range of pressures, as is seen on the index-plate, *M N*, on the pendulum, *H H*, where the large figures represent the total pressures on the journal, and those opposite the corresponding pressure per square inch.

The speed of the machine, when the belt is upon the largest pulley of the cone, *C*, should be that which will give the least speed of rubbing at the surface of the testing journal, which is to be usually adopted.

The figures on arc, *P P'*, traversed by the pointer, *O*, attached to the pendulum, are such that the quotient of the reading on the arc, *P P'*, by the total pressure read from the front of the pendulum at *M N*, gives the "coefficient of friction," *i. e.*., the proportion of that pressure which measures the resistance due to friction.

A printed table is furnished with each machine, giving these coefficients for a wide range of pressures and arc-readings.

*To determine the lubricating quality*, we remove the pendulum, *H H*, from testing journal, *G G'*, adjust the machine to run at the desired pressure, by turning the screw-head, *K*, projecting from the lower end of the pendulum, until the index, *M*, above, shows the right pressure, and adjust it to run at the required speed by placing the belt on the right pulley, *C*.

We then throw out the bearings by means of the two little cams on the head of the pendulum, *H*, in the small machine, or by setting down the brass nut immediately under the head in the large machine; we next carefully slide the pendulum upon the testing journal, *G G'*, and see that no scratching of journal or brasses takes place.

Then we oil the journal through the oil-cups or the oil holes, set the machine in motion, running it a moment until the oil is well distributed over the journal.

Next stop the machine; loosen the nut or the cams which confine the spring, and, when it is fairly in contact and bearing on the lower brass with full pressure, turn the brass nut or the cams fairly out of contact, so that the spring may not be jammed by their shaking back while working. Now, start the machine again, and run until the

behavior of the oil is determined, keeping up a free feed throughout the experiment.

At intervals of one or more minutes, as may prove most satisfactory, observe and record the temperature given by the thermometer, $Q$ $Q'$, and the reading indicated on the arc, $P'$, of the machine, by the pointer, $O$. When both readings have ceased to vary, the experiment may be terminated.

Remove the pendulum, first relieving the pressure of the spring, and clean the journal and brasses with exceedingly great care from every sign of grease; and be especially careful not to have a particle of lint on either surface, or any grease in the oil-cup or oil-passages.

A comparison of the results thus obtained with several oils will show their relative values as reducers of friction.

In each case we record in tables like the blanks, which are sent with the machine:

1. The pressure and speed of rubbing at each trial.
2. The observed temperature.
3. The readings on the arc of the machine, *i. e.*, the frictional resistance in pounds.
4. The calculated coefficients of friction.

We enter at the end of the trial the average and the minimum coefficients, and the total distance *rubbed over* by the bearing surfaces.

*To determine the liability of the oil to gum*, we allow the machine to stand with the journal wet with oil, but with none feeding through the bearing, for 12 or 24 hours or more, as may be found necessary. Then start up and run a few moments until the reading on the arc, $P$ $P'$, having fallen to a minimum, begins to rise again; then stop *at once*. Compare the minimum coefficients thus obtained from the several oils to be examined; that which gives the smallest figure will be least liable to gum during the period of time given to the test.

*To determine durability*, we proceed as in determining the friction, excepting that the lubricant should not be continuously supplied, but should be fed to the bearing, a small and definite portion at a time—say a drop for each two inches length of journal. Extreme care should be taken that each portion actually reaches the journal and is not lost, either in the oil-hole or by being wiped off the journal, and that the portions applied are *exactly* equal.

When the friction, as shown by the pointer, *O*, has passed a minimum and begins to rise, the machine should be carefully watched, and should be stopped either at the *instant* that the friction has reached double the minimum, or when the thermometer indicates 212° F.; or else another portion of the lubricant should be then applied to the journal.

This operation should be repeated until the duration of each trial becomes nearly the same; an average may then be taken either of the time, of the number of revolutions, or of the distance rubbed over by the bearing, which average will measure the durability of that lubricant.

Next, we carefully clean the testing-journal and proceed as before with the next oil to be tested.

In making comparisons we always test the standard, as well as the competing oils, on the same journal, and under *precisely* the same conditions.

An approximate value, by which to compare the oils, can be calculated, based on the assumption that they will have a money-value proportionate to their durability and to the *inverse* ratio of the value of the coefficient of friction.

The larger machine is built to a scale about three times as great as that of the smaller, just described, and has a journal of standard car-axle size, 3¼ inches diameter and 7 inches long.

The speed is intended to be adjusted to speeds varying from that of a 26-inch engine-truck wheel at 60 miles an hour, down to that of a 42-inch wheel running 15 miles an hour. The pressures are adjustable from a few pounds total pressure up to 400 pounds per square inch, or a load of nearly 10,000 pounds on the journal.

Fig. 3 is a side elevation of the larger machine, with the journal and pendulum in section; and Fig. 4, a front elevation. It consists of a shaft, *A B*, which is driven by a cone pulley, *C*, the whole mounted on a cast-iron stand, *D*, terminating in a forked end at the top, with two bearings, *E* and *F*, in which the shaft runs. The shaft projects beyond the journal, *F;* and the projecting part, *A*, is provided with a sleeve or bushing, *m m*, the outside of which forms a journal on which the tests of oil are made. A pendulum, *A G*, is suspended from this journal with suitable bearings, *a a*, which work on the journal, *m m*. A heavy weight, *G*, is attached to the lower end of the pendulum. It is evident that the friction on the journal, *m m*,

will have a tendency to move the pendulum in the direction of the revolution of the shaft and that the greater the friction on the journal the farther will the pendulum swing. A scale or dial, *H I*, is attached to the stand, and the distance the pendulum swings may be read off on this scale, which thus indicates the coefficient of friction of the lubricant on the journal. In order to get any desired pressure of the bearings on the journal, the pendulum is constructed as follows: A wrought-iron pipe, *J*, which is represented in Fig. 3 by

FIG. 3.

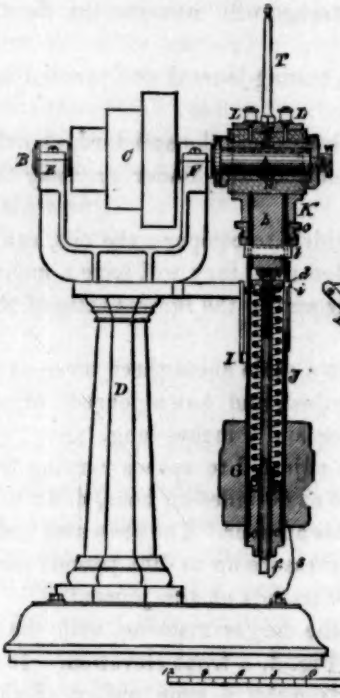
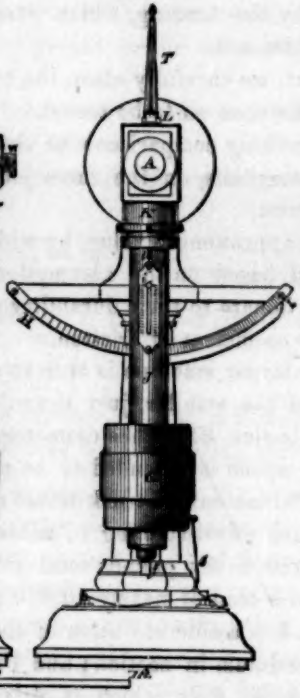


FIG. 4.



solid black shading, is screwed into the head, *K*, which embraces the journal and holds the bearings, *a a*, in their place. In this pipe a loose piece, *b*, is fitted, which bears against the under journal-bearing, *a'*. Into the lower end of the pipe a piece, *c c*, is screwed with a hole drilled in the centre through which a rod, *f*, passes, the upper end of which is screwed into a cap, *d*. Between this cap and the lower piece, *c c*, a spiral spring, shown in section in Fig. 3 is placed.

The upper end of the rod has a cap, *e*, in which it turns, and which bears against the piece, *b*, which in turn bears against the bearing *a'*.

If the rod is turned with a wrench applied to the square head at *f*, it is obvious that the cap, *d*, will be either drawn down on the spiral spring, which will thus be compressed, or it will be moved upward, and the spring will thus be released, according to the direction in which the rod is turned. If the spring is compressed, its lower end will bear against the under cap and on the piece, *c c*, by which the pressure will be transmitted to the pipe, *J*, and thence to the head, *K*, and from that on the upper journal-bearing, *a*; while at the same time the upper end of the spring bears against the cap, *d*, which, being screwed on the rod, *f*, transmits its pressure upward to the cap, *e*, and from that to the loose piece, *b*, and from that to the under journal-bearing, *a'*. It will thus be seen that any desired pressure, within the limits of the elasticity of the spiral spring, may be brought upon the journal and bearings by turning the rod, *f*. The piece, *b*, has a key, *l*, which passes through it and the pipe, *J*. This key bears against a nut, *o*, which is screwed on the pipe, its object being to provide a ready means of relieving the journal of pressure by simply turning the nut, *o*, when it is desired to do so. An index, *i*, is attached to the spiral spring, so as to show the position of the latter. The oil is fed to the journal by means of oil-cups, *L L*, on top of the head, *K*, and a thermometer, *t*, is attached between the two cups, and from it the rise in temperature is observed. A strap, *s*, is attached to the pendulum, to prevent it from being thrown beyond the limits provided for it.

The earliest determinations published, were given in the *Polytechnic Review*, March 3d, 1877. Later results were given in a lecture before the Master Car-Builders' Association, in New York, Dec. 20th, 1877[i]; and still later figures were given the Am. Railroad Master Mechanics' Association, at their annual convention held at Richmond, in the spring of 1878.[ii]

In the course of this long series of experiments, extending over several years, and including work on all standard lubricating materials, and under pressures varying from 0 to 1000 pounds per square inch, at speeds of rubbing reaching 1200 feet per minute, and at all attainable temperatures, as well as with a great variety of material in journals and bearings, it was found that instead of being

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[i] *Railroad Gazette*, Jan. 18th, 1878, p. 23.

[ii] *Railroad Gazette*, Aug. 2d, 1878, p. 384.

nearly constant in value, for even free lubrication, as assumed by engineers and physicists generally, the coefficient is variable in a marked degree by every change of pressure and of temperature; that it is affected by velocity-changes, and by the character of the metals of the journal and its bearings. A new journal also gives a coefficient which usually decreases, first rapidly, then more and more slowly, as it wears, while heating, and especially "cutting," causing an immediate and great increase of friction.

*Friction with Varying Pressures.*—An attempt was finally made to systematically determine the laws governing these variations of frictional resistance. A smooth journal, running in well-worn bearings, was lubricated with pure sperm oil, and the coefficients determined for a wide range of temperature, pressure and speed of rubbing.

The following table contains data secured during one part of this investigation.

Studying table A, we see that the coefficient rapidly diminishes with increase of pressure, until a pressure of over 500 pounds per square inch is attained; the coefficient, after passing a pressure of probably 600 to 800 pounds per square inch, increases, and, at 1000 pounds, becomes about equal to that obtained at 100 pounds. It will be remembered that 500 or 600 pounds pressure is usually considered to be a limit not to be exceeded in general practice in machine construction and operation.

Nevertheless, it is not uncommon to find as high pressures as 1000, or even 1200, pounds in the crank-pins of steam-engines. In such cases, however, the pins are almost invariably of steel, and the journals of good bronze—conditions which are less seldom met with elsewhere. There is also, in this case, as wherever a "reciprocating force" acts to move a piece, a condition which permits higher pressures to be successfully worked than can be reached elsewhere; the alternate application and relief of pressure, occurring between journal and bearing at each change of direction of the driving force, causes a release at such times, which permits the oil to find its way between the rubbing surfaces, and its expulsion is not then fully effected before the succeeding relief of pressure again permits its renewal. A somewhat similar action is consequent upon the rise and fall of a locomotive, or of a railroad car, in its springs, as it rapidly traverses even a smooth track.

TABLE A.—COEFFICIENTS OF FRICTION OF MOTION AND OF REST.—THURSTON.

(*a*) CAST IRON JOURNAL AND STEEL BEARINGS.

| PRESSURES PER SQUARE INCH. Pounds. | WINTER BLEACHED SPERM OIL. | | | WEST VIRGINIA OIL (MINERAL). | | | LARD OIL. | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | At 150 ft. per minute. $f$. | At Starting. $f'$. | At Stopping. $f''$. | At 150 ft. per minute. $f$. | At Starting. $f'$ | At Stopping. $f''$. | At 150 ft. per minute. $f$. | At Starting. $f'$. | At Stopping. $f''$. | |
| 50 | ·013 | .070 | ·030 | ·0213 | ·110 | ·025 | ·0200 | ·070 | ·010 | Temperature in all cases, less than 115° F. |
| 100 | ·008 | ·135 | ·025 | ·0150 | ·135 | ·025 | ·0137 | ·110 | ·022 | |
| 250 | ·005 | ·140 | ·040 | ·0090 | ·140 | ·026 | ·0085 | ·110 | ·016 | |
| 500 | ·004 | ·150 | ·030 | ·0052 | ·150 | ·018 | ·0052 | ·100 | ·016 | |
| 750 | 0043 | ·185 | ·030 | ·0050 | ·185 | ·014 | ·0066 | ·120 | ·020 | |
| 1000 | ·0090 | ·180 | ·030 | ·0100 | ·180 | ·017 | ·0125 | ·120 | ·019 | |

(*b*) STEEL JOURNAL AND BRASS BEARINGS.

| | | | | | | | | | | Ratio of $\frac{b}{a}$. | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | SPERM. | LARD. |
| 500 | ·0030 | | | | | | ·004 | | | ·75 | ·80 |
| 1000 | ·0080 | | | | | | ·009 | | | ·88 | ·90 |

Where, as in our testing-machine, under a flywheel-shaft, or in other machines, this relief cannot take place, the limit of pressure is earlier met.

Referring again to the last table, it is seen that between 100 and 750 pounds, the value of the coefficient may be obtained approximately by the expression,

$$f = \frac{a}{\sqrt{P}},$$

in which $a$ is a constant quantity, and $P$ is the pressure in pounds per square inch; for sperm oil, $a = 0{\cdot}100$; for the best crude heavy mineral oil, $a = 0{\cdot}150$; and for lard oil, $a = 0{\cdot}125$.[1]

It will be presently seen that the law is modified by temperature and speed.

The following data were given by trials of two excellent kinds of grease and of sperm oil compared with them as standard:

COEFFICIENTS OF FRICTION OF GREASES—THURSTON.

Steel Journal; Bronze Bearings; Velocity, 300 feet per minute.

| LUBRICANT. | PRESSURES, POUNDS PER SQUARE INCH. | | | | | |
|---|---|---|---|---|---|---|
| | 100 | 200 | 300 | 400 | 500 | Average. |
| Sperm Oil, . | ·0141 | ·0063 | ·0049 | ·0042 | ·0039 | ·0067 |
| Grease, No. 1, | ·0249 | ·0146 | ·0125 | ·0105 | ·0114 | ·0140 |
| " No. 2, | ·0188 | ·0198 | ·0160 | ·0146 | ·0175 | ·0173 |

Their relative average values, in reducing friction, stand, therefore: sperm, 100; No. 1, 44·8; No. 2, 37·7; which figures would also represent their relative money values, if estimated on that basis simply.

The method of variation with pressure, already noted, is here again illustrated, although the mathematical expression has a different set of constants, and the variation, at this speed, is more nearly as the inverse ratio of the cube root of the pressure.

[1] Some of these facts and deductions were published originally in a paper prepared in the spring of the year 1878, and read at the St. Louis meeting of the Am. Assoc. for Advancement of Science. This paper includes work done up to that time, supplemented by the more complete investigations since made. The research is still in progress, and determinations for other conditions will be published when obtained.

*Friction of Quiescence.*—In table A is presented a set of figures which are both new and important. In the columns headed "At 150 feet per minute," are given the coefficients of friction at the several pressures, as given when the rubbing surfaces are in motion at that relative velocity. These are the common and most usually required figures. We have given in the other columns, however, values which are seen at a glance to be immensely greater, and of which the values vary by an entirely different law. The first set, "At starting," are the well understood coefficients of friction of rest, varying with the pressure and with the nature of the unguent from 0·07 to 0·18. These values have, I think, never been determined before in this way, and possess great importance, not simply intrinsically, but also as throwing some light upon the effect of motion upon the efficacy of lubrication. It is seen that they increase with the pressure, instead of diminishing as do the coefficients of friction of motion; and that, at the highest pressures, their values become from ten to forty times the corresponding values of the latter. It is thus seen that, in the effort required to move heavy machinery, vastly greater force is demanded to overcome friction at the instant of starting, than after motion has once commenced. I presume that every experienced engineer or mechanic has known instances in which this difference has been so marked as to cause great difficulty in starting a machine which, once in motion, moved with comparative ease.

The method of variation of the coefficient for rest, is seen by reference to the table, to be such that their numerical values may be approximately estimated, for the cases here considered, by the formula,

$$f = 0{\cdot}a' \sqrt[3]{P},$$

in which $a' = 0{\cdot}02$ for sperm and heavy mineral oil, and $a' = 0{\cdot}015$ for lard oil.[1]

The figures in the columns headed "At stopping," were given while the machine was rapidly coming to a stop, after the driving belt had been shifted to the loose pulley. They are, as would be expected, intermediate in value between the other figures, and have, apparently, no practical importance. They may be taken as constant at all pressures.

[1] See paper, by the author, in Proceedings of Am. Assoc. for Advancement of Science, St. Louis meeting, 1878.

## Table B.—Coefficients of Friction.—Thurston.

New Journal of Steel; Bearings of Bronze; Velocity, Pressure and Temperature, Variable; Lubricant, Standard Sperm Oil.

| Speed per minute. | 30 Feet per Minute. | | | | | 100 Feet per Minute. | | | | | 250 Feet per Minute. | | 500 Feet per Minute. | | 1200 Feet per Minute. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pressure per sq. inch. Pounds. | 200 | 150 | 100 | 50 | 4 | 200 | 150 | 100 | 50 | 4 | 200 | 100 | 200 | 100 | 200 | 150 | 100 |
| Temp. Fahr. | | | | | | | | | | | | | | | | | |
| 175° | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ·0050 | ..... | ..... |
| 170 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ·0053 | ·0050 | ·0061 |
| 165 | ..... | ..... ..... | ..... | ·0200 | ·125 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ·0056 | ·0050 | ·0061 |
| 160 | ..... | ..... | ..... | ·0175 | ·125 | ·0280 | ..... | ·0025 | ·0037 | ..... | ..... | ..... | ..... | ..... | ·0056 | ·0053 | ·0061 |
| 155 | ..... | ..... .. | ..... | ·0137 | ·125 | 0190 | ·0110 | ·0025 | ·0037 | ..... | ..... | ..... | ..... | ·0037 | ·0056 | ·0058 | ·0061 |
| 150 | ·0500 | ·0500 | ·0250 | ·0125 | ·125 | ·0140 | ·0074 | ·0025 | ·0037 | ·0630 | ·0047 | ·0028 | ·0053 | ·0037 | ·0060 | ·0058 | 0061 |
| 145 | ..... | ..... | ..... | ·0112 | ·125 | ·0110 | ·0058 | ·0025 | ·0037 | ·0630 | ..... | ..... | ..... | ..... | ·0060 | ·0058 | ·0070 |
| 140 | ·0250 | ·0330 | ·0110 | ·0087 | ·125 | ·0100 | ·0050 | ·0025 | ·0037 | ·0630 | ·0047 | ·0030 | ·0053 | ·0037 | ·0062 | ·0058 | ·0070 |
| 130 | ·0160 | ·0200 | ·0044 | ·0075 | ·125 | ·0087 | ·0041 | ·0019 | ·0037 | ·0630 | ·0047 | ·0030 | ·0053 | ·0037 | ·0065 | ·0062 | ·0075 |
| 120 | ·0110 | ·0110 | ·0044 | ·0075 | ·125 | ·0056 | ·0035 | ·0019 | ·0037 | ·0630 | ·0047 | ·0037 | ·0056 | ·0037 | ·0069 | ·0067 | ·0080 |
| 115 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... ..... | ..... | ..... | ·0048 | ..... | ·0060 | ·0044 | ..... | ..... | ..... |
| 110 | ·0100 | ·0033 | ·0037 | ·0062 | ·094 | ·0044 | ·0033 | ·0019 | ·0037 | ·0630 | ·0050 | ·0044 | ·0062 | ·0050 | ·0075 | ·0075 | ·0087 |
| 100 | ·0075 | ·0028 | ·0031 | ·0056 | ·094 | ·0040 | ·0033 | ·0019 | ·0037 | ·0630 | ·0056 | ·0045 | ·0065 | ·0061 | ·0081 | ·0083 | ·0094 |
| 95 | ·0060 | ·0025 | ·0031 | ·0050 | ·094 | ·0040 | ·0033 | ·0019 | ·0037 | ·0630 | ·0062 | ·0050 | ·0072 | ·0061 | ·0087 | ·0092 | ·0125 |
| 90 | ·0056 | ·0025 | ·0031 | ·0037 | ·094 | ·0040 | ·0033 | ·0019 | ·0037 | ·0630 | ·0070 | ·0052 | ·0075 | ·0061 | ·0100 | ·0170 | ·0150 |

*Friction with Varying Velocity—Thurston.*—Refering to the accompanying Table B, in which the effects of varying velocities, as well as of coincident variation of pressure and of temperature, are exhibited, as given by experiment in the Mechanical Laboratory of the Stevens' Institute of Technology, it is readily seen that the change in value of the coefficient of friction with change of velocity is not great for machinery in which that velocity remains within usual limits, and at the usual temperature of a cool and properly working journal. The effect of change of velocity varies, as is here shown, with change of temperature and of pressure.

For cool journals in good condition, lubricated with good sperm oil, and between the limits of 100 and 1200 feet per minute, these values may be taken as varying approximately as the fifth root of the speed of rubbing, *i. e.*,

$$f = a \sqrt[5]{V}.$$

At a constant pressure of, say, 200 pounds, we may call $a = 0{\cdot}0015$.

*Friction with Pressure and Velocity Varying Simultaneously.*—We may now readily construct an equation which shall give values of the coefficient of friction for good journals lubricated with sperm oil, and for all ordinary variations both of pressure and velocity, since $f \propto \sqrt[5]{V}$, and $f \propto \sqrt[5]{P}$, we have approximately,

$$f = a \frac{\sqrt[5]{V}}{\sqrt[5]{P}},$$

in which we may take $a = 0{\cdot}02$ to $0{\cdot}03$ for general use.[1]

The value of $a$ for other conditions, and with other materials, may be determined by a comparison, by means of the testing-machine, of those materials under the assumed conditions, with those obtained with the standard oil under standard conditions, as here given.

*Friction with Varying Pressures, Speeds and Temperatures.*—We have here some exceedingly interesting data. The following were obtained by heating the bearing by its own friction to a maximum, 170° Fahr., well within that liable to produce alterations of the oil, and noting the temperatures while cooling. It should be remembered that no temperature-reading can be taken as more than approximate.

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[1] *Vide* paper, by the author, "On Friction Measurement," etc., Proc. Am. Assoc. for Advancement of Science, 1878.

## Friction and Temperature—Thurston.

Steel Journal; Bronze Bearings; Lubricant, Sperm Oil; Velocity, 30 feet per minute.

| Pressure per Square Inch. | Temperature, Fahr. | Coefficient of Friction. *f.* | Pressure per Square Inch. | Temperature, Fahr. | Coefficient of Friction. *f.* |
|---|---|---|---|---|---|
| 200 | 150 | 0·0500 | 150 | 110 | 0·0035 |
| 200 | 140 | 0·0250 | 100 | 110 | 0·0025 |
| 200 | 130 | 0·0160 | 50 | 110 | 0·0035 |
| 200 | 120 | 0·0110 | 4 | 110 | 0·0500 |
| 200 | 110 | 0·0100 | | | |
| 200 | 100 | 0·0075 | 200 | 90 | 0·0040 |
| 200 | 95 | 0·0060 | 150 | 90 | 0·0025 |
| 200 | 90 | 0·0056 | 100 | 90 | 0·0025 |
| | | | 50 | 90 | 0 0035 |
| | | | 4 | 90 | 0·0400 |

The figures just given would indicate that the sperm oil used in this instance, and under these conditions including that of exceptionally low speed, works best at lowest temperatures, and that a heating journal gives rapidly increasing friction and rapidly increasing danger. At usual temperatures, 90° to 110° Fahr., the best pressure seems to have been from 100 to 150 pounds on the square inch.

It would, however, be wrong to predicate general conclusions on such limited data, and the study of Table B is exceedingly interesting and instructive.

There are there given coefficients of friction for temperatures from 90° to 150° F., for pressures up to 200 pounds per square inch, and for velocities of rubbing up to 1200 feet per minute. This table is, in fact, a compendium of data for all ordinary conditions of the working of light and of moderately heavy machinery.

We find there some exceedingly valuable and very curious facts, bearing directly on our our everyday work.

We have seen that at the low speed of thirty feet per minute, the coefficient increases rapidly with increase of temperature, and that at 200 pounds pressure an increase of 50° F. may increase its value to nearly ten times the minimum, the rate of increase rapidly rising as pressures are greater.

We now find, at speeds of 100 feet per minute, that the friction does not vary between 90° and 150° F. at pressures below 50 pounds per square inch, but that it rises nearly 300 per cent. at a pressure of 200 pounds, over 100 per cent. at 150 pounds, and 33 per cent. at 100 pounds.

At speeds exceeding 100 feet per minute, heating the journal within this range of temperature *decreases* the resistance due to friction, rapidly at first, then slowly and gradually a temperature is approached at which increase takes place and progresses at a rapidly accelerating rate. It is seen that this change of law takes place at a temperature of 120° F. and upward, at all higher speeds the decrease continues until temperatures are attained exceeding those usually permitted in machinery, and very commonly not far from 150° F., and sometimes up to 180 F., or probably even higher. I have found the decrease, at 1200 feet per minute, to continue up to 175° F., at which the value at 200 pounds pressure was, in the cases determined, 0·0050. The limit of decrease is reached, under 100 pounds pressure, at 150° F. when running at this high speed.

At 200 pounds pressure, the *temperature of minimum friction*, for conditions here illustrated, seems to be, in Fahrenheit degrees, about

$$t = 15\sqrt[4]{V}.$$

On either side this point on the thermometric scale, it may be assumed, for a narrow range, to vary, as the temperature departs from that point, directly or inversely, as the case may be, as the temperature. The fact is, however, that this coefficient of minimum friction is found, usually, over quite a wide range of temperature.

Again, studying in this most instructive of our tables the method of variation with pressure at higher temperatures, we find the effect of change of pressure to be much more marked at the higher temperatures with low speeds; and, singularly enough, as when studying the effect of variation of friction with change of temperature at a standard pressure as affected by the variation of speed, we here find a change of law for the higher speeds.

At a velocity of 1200 feet per minute, the coefficient remains practically uniform with varying pressure at 150° Fahr.; while below that temperature, the friction-coefficient diminishes with increasing pressure. At velocities of rubbing of 250 to 500 feet per minute, the temperature of the constant coefficient is about 100°; at 100

feet this peculiar condition is seen at about 120°, when extreme pressures (4 pounds and 200) are compared, but the value is seen to be a little over one-half as much at 50 and 150 pounds, and to become a minimum—0·0019—at 100 pounds pressure, a similar behavior is noted at the lowest speed observed—30 feet—at about 125° F., and the same fall to a minimum at the intermediate pressure.

It would seem that, at all times, there is a tendency to acceleration of outflow from the journal, with increasing fluidity due to increasing temperature, which tends to cause an increase of friction; while the effort of capillarity to resist this outflow, seems effectively aided by increasing the velocity of rubbing.

A *balance* between these opposite influences is seen to take place at the slowest speed, when the pressure is somewhere below 4 pounds per square inch; this occurs at a speed of 100 feet per minute, at a pressure of 50 pounds; at 250 feet when the pressure becomes about 150 pounds; probably, it happens at the speed of 500, at somewhere about the same point, and at 1200 feet per minute the benefit of increased speed is sufficient to produce this balance when the pressure exceeds 200 pounds per square inch.

These data would seem to give very useful information relating to the method of action of lubricating materials.

*Finally*, it has now become evident that such a series of comparisons as I have here made, are needed in every case in which the real value and the extent and the conditions of application of any single oil, or other unguent, are to be learned. Such a systematic examination reveals precisely the conditions which the lubricant best meets, and tells, with a certainty, at what pressure and at what speed it does its best work.

Conversely, the speed, the pressure and other conditions of working being known, a reference to a set of such determinations for various lubricants being made, it is easy to ascertain at once which is best adapted to the work in view.

Thus, having had occasion to determine the value of the friction-coefficients of a material having a very high reputation as a "cylinder oil"—*i. e.*, an oil for use in the cylinders of steam-engines,—it was found that its distinguishing peculiarity, as compared with oils not specially adapted for such purpose, was a continually diminishing coefficient, quite up to the limit of temperature of locomotive steam-pressure.

Any new lubricant should always have its true value and best adaptations thus determined. I have presented the figures for a fine steel journal, running in good bronze bearings and lubricated with sperm oil, not simply as an illustration, but principally as representative of the best set of conditions for use as a *standard* in making comparisons of other unguents of less value, or less known, or under less favorable conditions.

## Conclusions.

Studying the facts here laid out, and the data acquired by many hundreds of other experiments made on one or the other of these last described machines for testing lubricants, we may now recapitulate facts and figures for ordinary use in machine-design and in estimating losses of power by friction.

1. The great cause of variation with well-cared-for journals is alteration of pressure, and it is seen that the higher pressures, within the range of these experiments, give the lowest percentages of loss of power by friction.

2. The value of the coefficient is greatly modified by the state of the rubbing surfaces; and the necessity of keeping journals in perfect order cannot be too strongly insisted upon. A single scratch has its effect in wasting power. A journal should have its surface as smooth and as absolutely uniform as a mirror. Every well-kept journal has such a surface.

3. For general purposes, the value of the coefficient may be obtained pretty closely by dividing 0·08 to 0·10 by the square-root of the pressure in pounds per square inch,—*i. e.*, $f = \frac{0{\cdot}10}{\sqrt{p}}$—in which case it is given as that fraction of the total pressure which measures the resistance due to friction.

4. The coefficient for rest or starting may similarly be taken as about 0·02 the cube-root of the pressure—*i. e.*, $f' = 0{\cdot}02\sqrt[3]{p}$—for sperm and for crude mineral oil of good body, and 0·015 the cube-root—*i. e.*, $f' = 0{\cdot}015\sqrt[3]{p}$—for lard oil. For closer estimates, the tables just given can be referred to directly. It would seem that each material has its own coefficient and its own appropriate exponent in the expression, $f = c\,P^x$.

5. The coefficient for the instant of coming to rest, under conditions such as are here given, is nearly constant and may be taken at 0·03.

6. The resistance due to friction varies with velocity, decreasing with increasing velocity, rapidly at very low speeds, as from 1 to 10 feet per second,[1] and slowly as higher speeds are reached, until the law changes, and increase, at ordinary temperatures, takes place and at a very low rate throughout the whole range of usual velocities of rubbing in machinery.

The value may be taken for use in machine-design and mill-work, and at a pressure of 200 pounds per inch, as $f = 0{\cdot}0015 \sqrt[5]{V}$.

7. With pressure and velocity varying we may take, roughly,

$$f = 0{\cdot}02 \frac{\sqrt[5]{V}}{\sqrt[3]{P}}, \text{ to } f = 0{\cdot}03 \frac{\sqrt[5]{V}}{\sqrt[3]{P}}.$$

8. That the effect of heating journals under conditions here illustrated is to *increase* the friction in proportion to the square of the increase of temperature above, say, 90° or 100° F., at a speed as low as 30 to 100 feet per minute, while at higher speeds the opposite effect is produced and the coefficient *decreases* more nearly as the square-root of the rise of temperature.

Under all conditions commonly met with by the maker of machines, the latter is the method of change.

9. The temperature of minimum friction, under the conditions of these experiments, is about $t = 15 \sqrt[5]{V}$ for a pressure of about 200 pounds per square inch.

10. The endurance of any lubricant should be determined by actually wearing it out upon a good journal under the pressures and velocities proposed for its use.

The economy with which it can be used will also be dependent upon its natural method and rate of flow, and upon its capillary qualities, as well as upon its intrinsic wearing-power, and the method adopted in feeding it. Greases, therefore, are usually more economical than oil, *even if having a less wearing capacity.*

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[1] We deduce this conclusion from the experiments of Professors Jenkin, Ewing and Kimball, at speeds below any given in this paper.

11. The only method of learning the true value of a lubricant and its applicability in the arts, is to place it under test, determining its friction-reducing power and its other valuable qualities, not only at a standard pressure and velocity and at ordinary temperatures, but measuring its friction and endurance as affected by changing temperature, speeds and pressures throughout the whole range of usual practice.

12. The true value of an oil to the consumer is not proportional simply to its friction-reducing power and endurance under the conditions of his work; but its value to him is measured by the difference in value of power expended, using different lubricants, less the difference in total cost of oil or grease used; but, for commercial purposes, no better method of grading prices seems practicable than that which makes their market-value proportional to their endurance divided by their coefficients of friction.

The consumer will usually find it economical to use that lubricant which is shown to be the best for his special case, without respect to price, and will often find the real economy in using the better material, sufficient to repay the excess in total cost very many times over. He cannot afford to accept low grade unguents, even without charge.

13. To secure maximum economy, the journal should be subjected to a pressure determinable by either Rankine's or Thurston's formula; the most efficient materials should be chosen for the rubbing surfaces; they should be reduced to the most perfect state of smoothness and perfection in form and fit; a lubricant should be chosen which is best adapted for use under the precise conditions assumed; the lubricant should be applied precisely as needed, and by a method perfectly adapted to the special unguent chosen.

The semi-fluid lubricants, if equally good reducers of friction, are usually most economical, in consequence of their peculiar self-regulating flow, as the rubbing parts warm or cool while working.

Where heating is not to be anticipated, maximum economy is obtained by the minimum rate of supply allowable only if that supply be maintained with absolute uniformity.

STEVENS' INSTITUTE OF TECHNOLOGY,
*Hoboken, N. J., Sept.*, 1878.

# ON THE DRIVING POWER OF LEATHER BELTS.

By J. H. Cooper.

One of the earliest attempts at investigating the essential conditions of driving belts and of formulating a rule and table for ready reference, is that of M. Laborde, dating prior to the year 1833. As his memoir is little known and not easily accessible, a correct presentation of his views is desirable, and to this end the literal rendering of his paper, together with data from other authorities for comparison, is given below.

It is worthy of note that M. Laborde derived his data from belts in use, and that he relied for years upon the rule which he has given.

After adopting a formula, based upon the area of contact, as the right measure for the transmitting power of a belt, introducing dimensions dictated by his own successful practice for a dynamic unit, we find our author stating distinctly the limitations of his rule to 180° of pulley contact, and granting to each user of belts the privilege of substituting his own unit of measure, well knowing the prevalence of differing opinions on this feature of the subject, as we find existing at this time, but of the reliability of the formula he is sure.

All subsequent writers on belting have reproduced Laborde's "well-known truths" in some form or other, which may be proven by reference to the ample quotations given in the writer's "Treatise on the Use of Belting."

These truths are readily deducible from his text, and are here condensed:—

The resistance to be overcome must be less than the force required to slip the belt.

The tension must not injure the belt.

The tension must not strain the shafts nor unnecessarily increase journal friction.

The belt must adapt itself perfectly to the pulley surface.

The belt should be of single thickness.

The pulley surfaces must be smooth.

A belt under like conditions will slip the same on large as on small pulleys.

The efficiency of a belt is as the product of its width and speed.

The best driving by belts is derived from the higher speeds; for low speeds gearing should be used, and generally:—

The efficiency of belts is best obtained from high speed, low tension and reduced width.

And, as for the rule, it will be necessary first to get exact dimensions of the belt he has chosen for the "starting point," in English measure, before comparison can be made.

The belt selected by M. Laborde which readily transmitted one French horse-power under safe tension, on smooth-faced pulleys of equal diameter, had a breadth of 3 *pouces* and 500 feet of speed per minute; but not having the means at hand of converting this unit of measure into English, I have taken Armengaud's figures of the same belt, which are 0·081 m. (= 3·189 inches) for the breadth and 162·50 m. (= 533 feet) for the speed, transmitting one *cheval* of 75 kilogrammetres (= ·986 English horse-power).

In other words, this belt had a surface velocity of 143·656 square feet per minute per horse-power and worked under a stress of 19·15 pounds per inch of width.

This tension is low compared with American practice, but other foreign writers have adopted near the same base as that of Laborde.

From "Tables, Rules and Data, by D. K. Clarke," London, 1877, I quote: "M. Claudel instances the common experience that a belt 3¼ inches broad, moving at a velocity of 9 feet per second, can very well transmit one horse-power with ordinary tension, and without over-straining, working on turned and smooth pulleys of equal diameter; the working tension is only about 20 pounds per inch wide."

It will be noticed how nearly Claudel's example of working belt corresponds with that of Laborde; it is probably the same.

"Dr. Hartig found, from experiments made by him in a woolen mill, that the tension of the driving belts varied from 30 pounds to 532 pounds per square inch of section, and that it averaged 273 pounds per square inch."

"An average working strength of 300 pounds per square inch of section of leather belts may be accepted for purposes of calculation."

M. Carillon, M.E., of Paris, quoted by Armengaud, employs as base, "A belt can transmit one horse-power, if it have a surface velocity of 96·9 square feet per minute, providing not less than one-third of the circumference of either pulley be embraced." This is

equivalent to a working stress of about 28 pounds per inch width of belt.

M. Morin I find variously quoted: 275, 284, 285 and 355 pounds per square inch of section for continuous working stress of belting leather, being attributed to him. Box gives 310, Haswell 350, Abel 320, and Webber adopts 330 for a purpose hereafter explained.

The thickness of belts is also differently stated; many writers name $\frac{3}{16} = \cdot 1875$ inch; Morin says, ·1575 to ·3150 inch; Webber, ·1666 inch, and Towne, $\frac{7}{32} = \cdot 219$ inch.

It is easy now to show the origin of different rules for the driving power of one inch width of belting, for if we take $350 \times \cdot 1875 = 65 \cdot 625$ pounds, we have the rule adopted by Briggs and Towne, and if we take $330 \times \cdot 1666 = 54 \cdot 978$ pounds, we have Webber's rule. Each starting from a different base, with different section of material.

In fact, a single leather belt in good driving condition will transmit 100 pounds to the inch of width, as shown in Art. 15, "Use of Belting."

We have, at this stage of the inquiry, at least reached the *extremes* of reliable practice—20 and 100 pounds driving-power to the inch width of single leather belting—it will not be difficult, then, to reconcile the differences of the *means*.

If, instead of taking Morin's highest figures for continuous working stress on belting leather, we approach a mean of the figures quoted, say 330 pounds—employing Webber's line of argument—we strike the component part of the horse-power unit, whence we reach the following convenient and reliable rules:—

330 pounds at 100 Fpm. = 33,000 pounds 1 Fpm.;

or 1 square inch of belting at 100 Fpm. = 1 horse-power.

If belting leather be $\frac{1}{3}$ inch thick, then,

1 inch width at 600 Fpm. = 1 horse-power; which proves that the old "rule of thumb" has foundation in fact.

Furthermore, $\frac{600}{12} = 50 =$ square feet of belt per minute per horse-power.

Also, we have $\frac{33000}{50 \times 12} = 55 =$ stress in pounds per inch of width.

And, finally, of rules it may be said the practical mechanic needs but one; for the ordinary cases of transmission of power by belting, and that one is a very simple statement:

*It is the stress in pounds which each inch of width of belt will safely and continuously bear at any velocity.*

From what is said above, the reader will clearly understand the practical range of belt capacity as given in the books. From Laborde's starting point of near 20 lbs., which is certainly safe, even with low quality of belting, to the greatest constant load, say 100 lbs., which a single leather belt will carry. Between these working limits, the choice of stress for belting will vary with the quality, section, length and condition of the belts employed, and with the proportion of pulleys and of speed in the system of mechanism of which they form a part.

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## RESEARCHES ON THE PRINCIPLE OF THE EMPLOYMENT OF BELTS FOR TRANSMITTING POWER.

By J. B. Laborde, M. E.[1]

The first idea which presents itself in this research is, that the resistance to be overcome must be less than the force which causes the belt to slip upon the circumference of the pulley. The second is, that the tension of a belt must not arrive at a point to stretch it, because it would be too quickly destroyed. The third is, that drawing too strongly upon the axes, the resistance increases, as if these axes were increased, in the same proportion in weight as is represented by the tension, which necessitates an increase in the strength of the journals.

Yet a fourth question presents itself: That a belt must be very flexible, or, to express it better, very supple, in order that the power employed to cause it continually to touch in all its parts, be as little as possible.

One can then conclude, with these four reflections, that a belt ought never to be doubled, but consist of a single thickness of leather, softened, when dry, with plain tallow; that it must never be employed at a tension which can stretch it to a point to deform it, and that it ought to adapt itself perfectly to the circumference of the pulleys; that for this reason, the pulleys must be turned smooth, and not ridged, neither lengthwise nor crosswise, as is often done.

These well-known truths have only helped us to find a rule which governs the breadth and the speed, according to the resistances to be overcome.

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[1] Laborde's original paper was published in the Bulletin of the Industrial Society of Mulhouse, Alsace; a MS. copy of this was kindly furnished by Mr. V. Steinlen, and loaned to the writer by Mr. R. Briggs.

If we wish to transmit power, the necessary force of which be represented by 7, and the breadth of the belt be represented by a number, for example 10, and by a speed of 100, it is evident that to transmit a double force, a breadth of 20 with a speed of 100 will be necessary; or 10 of breadth with 200 of speed; or briefly, there is necessary a breadth and a speed, such that their product, comparative at first, be in the ratio of 2 to 1; hence we can conclude that the forces to be transmitted are to each other as the products of the breadths of the belts, multiplied by their speeds.

Then calling $f'$ a known force taken for a base, $l'$ a known breadth; $v'$ a known speed, taken equally for a base. Calling, also, $f''$ any force whatever, $l''$ a breadth, and $v''$ a speed in the product, let it be relative to this force whatever, and we shall have the following proportion:

$$f' : f'' :: l' v' : l'' v'', \text{ or } f' l'' v'' = f'' l' v',$$

which will be the general formula.

It is then no longer the question to find, in practice, a base or starting point.

Here each practitioner can vary his opinions on the adoption of this base, but all must be in accordance with the formula.

My experience has shown me, as a good base, that the force of 6 men, or of a horse, or, to express it better, a dynamic unity, is transmitted very well with a breadth of 3 inches (*pouces*), and 500 feet of speed per minute. Such a belt acting upon a non-ridged pulley, *i. e.*, smoothly turned, has no need of a strong tension, and does not deform itself. It is well understood that this refers to a half-embraced pulley, for in transmissions where the pulleys are embraced but a fourth or a sixth, we must modify the rule, but the base is correct, whatever the diameter of the pulley may be; and, in fact, if the pulley be 5 feet in circumference, it will make 100 turns per minute, but if it be only $2\frac{1}{2}$ feet, it will make 200 turns; it will then, during the same time, have presented the same surface to the action of the belt; which explains why, when a large or a small pulley, each half-embraced by the belt, the belt does not slip sooner on one than on the other. (However, we must not descend to the infinitely small, for then the movements will be defective.)

According to the statements which my experiment has shown me as a good case, I have drawn up the following table, which has served me as a guide in my applications for the last ten years:

## Table showing the Breadths of Belts according to their Speeds and the Motive Forces which are to be Transmitted.

$F'$ = 1 horse-power.
$L'$ = 3″ breadth of belt. } Case.
$V'$ = 500 feet of speed.

Formula $F' L'' V'' = F'' L' V'$.

SPEEDS PER MINUTE EXPRESSED IN FEET.

Of the Table. { $F''$ = motive forces. $L''$ = corresponding breadths. $V''$ = different speeds.

| Forces to be transmitted. | | 3000 | 2500 | 2000 | 1600 | 1200 | 1000 | 800 | 650 | 500 | 400 | 325 | 275 | 225 | 175 | 140 | 100 | 75 | 50 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Men. | Horses. | Proportional Breadths in Inches, Lines and Points. | | | | | | | | | | | | | | | | | |
| | | I. L. | I. L.P. | I. L.P. | I. L.P. | I. L.P. | I. L. | I. L. | I. L. | I. L. | I. L. | I. L. | I. L. | I. L. | I. L. | I. L. | I. L. | I. L. | I. |
| 1 | | 0 1 | 0 1·2 | 0 1·5 | 0 1·9 | 0 2·5 | 0 3 | 0 4 | 0 5 | 0 6 | 0 7 | 0 9 | 0 11 | 1 1 | 1 5 | 1 9 | 2 6 | 3 4 | 5 |
| 2 | | 0 2 | 0 2·4 | 0 3· | 0 3·8 | 0 5· | 0 6 | 0 7 | 0 9 | 1 0 | 1 2 | 1 6 | 1 10 | 2 3 | 2 10 | 3 6 | 5 0 | 6 8 | 10 |
| 3 | | 0 3 | 0 3·6 | 0 4·5 | 0 5·7 | 0 7·5 | 0 9 | 0 11 | 1 2 | 1 6 | 1 9 | 2 3 | 2 9 | 3 4 | 4 3 | 5 7 | 7 6 | 10 0 | 15 |
| 4 | | 0 4 | 0 4·8 | 0 6· | 0 7·6 | 0 10· | 1 0 | 1 3 | 1 6 | 2 0 | 2 4 | 3 0 | 3 8 | 4 5 | 5 8 | 7 0 | 10 0 | 13 4 | 20 |
| 5 | | 0 5 | 0 6· | 0 7·5 | 0 9·5 | 1 0· | 1 3 | 1 7 | 1 11 | 2 6 | 2 11 | 3 9 | 4 7 | 5 6 | 7 1 | 8 9 | 12 0 | 16 8 | 25 |
| 6 | 1 | 0 6 | 0 7·2 | 0 9· | 0 11·4 | 1 2· | 1 6 | 1 10 | 2 4 | 3 0 | 3 6 | 4 6 | 5 5 | 6 8 | 8 7 | 10 7 | 15 0 | 20 0 | 30 |
| | 2 | 1 0 | 1 2·4 | 1 6· | 1 11· | 2 4· | 3 0 | 3 8 | 4 7 | 6 0 | 7 0 | 9 0 | 10 10 | 13 4 | 17 1 | 21 1 | 30 0 | 40 0 | 60 |
| | 3 | 1 6 | 1 9·6 | 2 3· | 2 10· | 3 6· | 4 6 | 5 7 | 6 11 | 9 0 | 10 6 | 13 6 | 16 4 | 19 11 | 25 7 | 31 8 | 45 0 | 60 0 | 90 |
| | 4 | 2 0 | 2 4·8 | 3 0· | 3 9· | 4 8· | 6 0 | 7 5 | 9 2 | 12 0 | 14 0 | 18 0 | 21 10 | 26 7 | 34 2 | 42 2 | 60 0 | 80 0 | 120 |
| | 5 | 2 6 | 3 0 | 3 9· | 4 9· | 6 0· | 7 6 | 9 3 | 11 6 | 15 0 | 17 6 | 22 6 | 27 3 | 33 3 | 42 9 | 52 9 | 75 0 | 100 0 | 150 |
| | 6 | 3 0 | 3 7· | 4 6· | 5 8· | 7 2· | 9 0 | 11 1 | 13 10 | 18 0 | 21 0 | 27 0 | 32 8 | 39 11 | 51 4 | 63 4 | 90 0 | 120 0 | 180 |
| | 7 | 3 6 | 4 2· | 5 3 | 6 8· | 8 4· | 10 6 | 13 0 | 16 1 | 21 0 | 24 6 | 31 6 | 38 2 | 46 3 | 59 10 | 73 10 | 105 0 | 140 0 | 210 |
| | 8 | 4 0 | 4 | 6 0 | 7 7· | 9 6· | 12 0 | 15 0 | 18 5 | 24 0 | 28 0 | 36 0 | 43 7 | 52 10 | 68 5 | 84 5 | 120 0 | 160 0 | 240 |
| | 9 | 4 6 | 5 4· | 6 9· | 8 7· | 10 8· | 13 6 | 16 8 | 20 8 | 27 0 | 31 6 | 40 6 | 50 0 | 59 6 | 76 11 | 95 0 | 135 0 | 180 0 | 270 |
| | 10 | 5 0 | 6 0· | 7 6· | 9 6· | 11 10· | 15 0 | 18 6 | 23 0 | 30 0 | 35 0 | 45 0 | 54 6 | 66 2 | 85 6 | 105 6 | 150 0 | 200 0 | 300 |

A C B D

This table clearly represents at a glance as to how far one can make use of belts to transmit power, and at what point to abandon them for gearing; for all that is below the line *C D* would be a very bad use of belting. For cases which lie between the lines *A B* and *C D*, two belts running 3 or 4 inches apart should be used.

It would be absurd, also, to think of making belts of one, two, three, etc. lines in width, for in order that a belt draw upon the pulley, it must be at least 2 inches wide, only it is not stretched at all, for example, the belts of stampers: that of a cotton stamper, according to calculation, would be sufficiently wide at 4 lines to drive it, but it is necessary to make them 2 inches wide in order that the velocity does not cause them to run off pulleys without grooves.

It is well to remark that on account of their excess of breadth, so much less tension is given to them; it is not the same with the driving belt of this machine, whose speed is 400 feet per minute, and at that speed has to overcome one horse-power.

The corresponding breadth in the table is found to be 3 inches 6 lines, and there is here no reason to modify the rule.

It is to be noticed, at the two extreme angles of the table, that a belt of 5 inches at a speed of 3000 feet can transmit a force of 10 horse-power, while the same belt at a speed of 50 feet can transmit only the power of one man.

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## ASTRONOMICAL FORECASTS.

By Pliny Earle Chase, LL.D., Professor of Philosophy in Haverford College.

Successful prediction furnishes the best possible test for any hypothesis. It is daily illustrated in the *experimentum crucis* of the chemist and physicist; astronomy has furnished two well-known instances, in the discovery of the asteroidal belt, and in the discovery of Neptune.

In the last number of this Journal,[1] I announced a second verification, which was also a sixth confirmation, both of a hypothesis and of an astronomical prediction which I published in 1873. In

[1] See p. 286.

the present paper I propose to give a complete series of such verifications and confirmations, together with a brief statement of the principles on which they are based. By a "confirmation," I mean any fact, whether previously known or not, which accords with a hypothesis; by a "verification," I mean a confirmation which was not known until after the hypothesis or prediction was published.

That the planets of the solar system, and the light-shedding orbs of stellar systems, are arranged in some kind of order, was known even before Job heard the voice which told of the time "when the morning stars sang together." In some foregoing articles,[1] on "The Music of the Spheres," "Planetary Mechanics," and "Music of the Moons," I set forth some of the most satisfactory cosmical groupings that have been discovered, and showed that those which were based upon laws of musical rhythm, or harmonical progression, showed the closest accordance with actual positions. Even as a bare matter of fact, this was interesting; if the fact can be traced to some general law, the interest must be largely increased.

When vibrations are set up in any elastic medium, there is always a tendency to the production of harmonic vibrations. If movable particles of matter come within the range of such vibrations, they will be driven away from the internodes and collect about the nodes. No other known medium has so great a degree of elasticity as the hypothetical æther, the medium which is supposed to produce, by its vibrations, the sensation of light. There is, therefore, an eminent reason why we should look for evidences of harmonic æthereal vibrations, provided we can find any sufficient cause for fundamental vibrations. Whether the assumed æther has a real existence or not, is a matter of no consequence. If we find an extensive series of phenomena which seem to be controlled by the laws of elasticity, we may reasonably use those laws as a help towards anticipating other phenomena of a like kind.

The wave-velocity, in an elastic atmosphere, is equivalent to $\sqrt{gh}$, or to $gt$, $g$ denoting the force of gravity at the point of observation; $h$, the "modulus of elasticity," or the height of a homogeneous atmosphere; $t$, the time of fall through $\frac{1}{2}h$, under the constant acceleration $g$, or the time of rise through $\frac{1}{2}h$, under the initial velocity $gt$, and constant retardation $g$. If circular or elliptical

[1] This JOURNAL, Sept., Oct., Nov., Dec., 1877.

orbits are produced by the alternate rise and fall which accompany such vibrations, and if the collision of orbital particles forms a rotating nucleus, the law of "conservation of areas" requires that $\sqrt{gh}=gt$ should be constant. At the centre of our system, if $t$ represents the time of a half rotation of the Sun, $gt$ is the velocity of light. This intimate dependence of solar rotation on light-velocity, must always have existed in the past, and will always exist in the future, through all possible stages of nebular condensation, unless there should be some contravening divine intervention.

This fundamental wave-velocity is about 487 times as great as the greatest velocity that can be communicated by solar attraction. Hence the orbital velocities of planets are relatively insignificant, and each planet forms a node of comparative rest in the æthereal sea. The most important node is formed by the Sun; the most important in the planetary belts, by Jupiter, which is nearly two and a half times as great as the aggregate sum of all its companion planets; the most important in the intra-asteroidal belt, by Earth, which is in the centre of the belt, and is also the largest of the dense planets.

We have already seen[1] that a primary harmony is set up by Neptune; that it is modified by Jupiter and Saturn; that the Jupiter harmony is the most extended of any, and that even Jupiter's influence is modified by Earth. According to the nebular hypothesis, when Sun was expanded to the present orbit of Jupiter, the collisions of subsiding particles would tend to form a ring at two-thirds the distance, or at 3·469 times Earth's mean radius-vector. If we take this as a new harmonic unit, $\frac{1}{1}$, we find that Venus's mean perihelion is well represented by $\frac{1}{3}$, Mercury's mean distance by $\frac{1}{5}$, and Kirkwood's estimated semi-major-axis of "Vulcan" by $\frac{1}{17}$. Here are, therefore, four terms of a new harmonic series, with a denominator difference of 4.

These indications were so striking, especially when taken in con nection with other rhythmical planetary series as to justify their announcement before the American Philosophical Society, at its meeting of May 2d, 1873.[ii] An abstract of the announcement was also published in the New York *Tribune* of the same date, special attention being called to the fourth term ($\frac{1}{13}$ of 3·469 = ·267), as indicating

[1] Loc. cit.

[ii] Proc. Soc. Phil. Amer., xiii, 238, 470, 472.

"a possible unknown planet, planetoid group, or other seat of solar and planetary perturbation." Forty-one days afterwards, on the 19th of June, Messrs. De la Rue, Stewart and Loewy made a communication to the Royal Society, in which they adduced evidence of tendencies in sun-spots "to change alternately from the North, or positive, to the South, or negative, hemisphere and *vice versa*," attaching special significance to the fact "that *the two outbreaks are at opposite ends of the same solar diameter.*" They assign "the most probable mean value, 25·2 days" for the interval between two maxima of the same sign. The interval between two maxima *of the same sign and originating in tidal disturbance at the same axial extremity* would, of course, be twice as great, and a planet or planetoid belt, with such an orbital period, would represent the first of the harmonic intra-Mercurial nodes. This was the fifth confirmation of my new series, and the first proper verification of my prediction.

At the time of the late total solar eclipse, Watson and Swift each observed two small planets in near proximity to the Sun. Two French astronomers, Gaillot and Mouchez, by comparing Watson's first announcement with some of the most trustworthy of the observations which have been collected by Leverrier, deduced a probable orbital period of 24·25 days, which satisfactorily represents my third intra-Mercurial position. Thus, after an interval of more than five years, comes the sixth confirmation and the second verification, both of my hypothesis and of my prediction. Could any *experimentum crucis* be more conclusive?

In "The Gamut of Light," "Planetary Mechanics," and "Elementary Spectral Harmonies,"[1] I have shown that spectral lines are harmonically arranged; that the same fundamental harmonic progression has influenced the solar spectrum and the positions of planets; that the masses of the four principal planets involve a figurate series which is also found in the arrangement of the Fraunhofer lines; and that all these results are simple consequences of the laws which govern synchronous vibrations in elastic media. In various communications to the American Philosophical Society, I have further shown that there are evidences of similar synchronism, under the influence of impulses which are propagated with the velocity of light, in heat, actinism, electricity, electro-magnetism, barometric fluctuations, ter-

[1] This JOURNAL, Sept., Oct., 1877, Jan., 1878.

restrial magnetism, chemical combination, and dissociation. If the energies of the earth "are all generated by a portion of the Sun's energy which does not amount to $\frac{1}{2800000000}$ of the whole,"[1] we may readily believe that the same energy which produces all these results, would suffice for the formation of cosmical nodes.

If a nebula condenses until all the particles in the equatorial plane have an orbital velocity, the mean radial *vis viva* at the orbital centre of linear oscillation ($\frac{1}{8}$ $r$), is equivalent to the orbital *vis viva* at 9 $r$. This equality may, perhaps, help to account for the following approximate division of the planetary system, the unit being Sun's radius:

| | | | |
|---|---|---|---|
| $9^2 r =$ | 81 $r$. | Mercury's mean radius-vector, | 83·17 $r$. |
| $9^3 r =$ | 729 $r$. | Asteroid 76, | 732·42 $r$. |
| $9^4 r =$ | 6561 $r$. | Neptune's mean radius-vector, | 6453·06 $r$. |

The relatively rapid motion of Phobos, the inner satellite of Mars, as well as the newly-found meteoroidal character of the corona, may reasonably lead us to look for an indefinite number of further verifications, among the results of future discovery. Many of them, like many of the Neptunian harmonies which are modified by the overshadowing mass of Jupiter, will probably elude all attempts at discovery, but the apparent importance of 9 as a cosmical factor, gives interest to the second series in the following table. The denominators, in the first series, are of the general form $(4n - 3)$; those in the second series are of the form $(4v - 3 = 144n - 111)$; $v$ being equivalent to $9(4n - 3)$.

FIRST SERIES.

| No. | Harmonic Prediction. | | Confirmation. | |
|---|---|---|---|---|
| 1 | $\frac{1}{1}$ | = 3·469 | Node of subsidence, | 3·469 |
| 2 | $\frac{1}{5}$ | ·694 | Venus m. p.,[a] | ·698 |
| 3 | $\frac{1}{9}$ | ·385 | Mercury m., | ·387 |
| 4 | $\frac{1}{13}$ | ·267 | De la Rue, S., and L., | ·267 |
| 5 | $\frac{1}{17}$ | ·204 | Kirkwood, | ·209 |
| 6 | $\frac{1}{21}$ | ·165 | Watson, | ·164 |

[1] "Heat as a Mode of Motion," N. Y. ed., 1873, p. 466.

[a] m., mean; p., perihelion.

## Second Series.

| No. | Harmonic Prediction. | | | Confirmation. | |
|---|---|---|---|---|---|
| 1 | $\frac{1}{8\,3}$ | = | ·1051 | Helios, | ·1060 |
| 2 | $\frac{1}{1\,7\,7}$ | | ·0196 | Themis, | ·0196 |
| 3 | $\frac{1}{3\,2\,1}$ | | ·0108 | Eunomia, | ·0108 |
| 4 | $\frac{1}{4\,6\,5}$ | | ·0074 | Phaos, | ·0075 |
| 5 | $\frac{1}{6\,0\,9}$ | | ·0057 | Lychnis, | ·0056 |
| 6 | $\frac{1}{7\,6\,8}$ | | ·0047 | Sun's surface, | ·0047 |

The first term of the second series, Helios, represents an orbital node in which the time of revolution would be synchronous with that of a solar half-rotation. This, as I have already said, is equivalent to the time in which the continuous acceleration or retardation of Sun's superficial gravitation, would communicate or overcome *the velocity of light*. In order to maintain equality of areas, the time of rotation, in an expanding or contracting nucleus, should vary as the square of radius. But $g$ varies inversely as the square of radius, so that $g\,t$ should be constant at all stages of solar condensation, past, present, or future.

The second term of the series, Themis, represents an orbital node in which planetary revolution would be accomplished in a sidereal day, or synchronously with Earth's rotation on its axis. The closeness of its relation to Earth, and its accordance with the laws of harmony, are both fitly designated by its name; Themis having been regarded as the daughter of Heaven and Earth, and as the goddess of law and order.

The third term of the series, Eunomia, represents an orbital node in which planetary revolution would be accomplished synchronously with Jupiter's rotation on its axis. Its designation has also a double fitness, for Eunomia was the mythical daughter of Jupiter and Themis, her name signifying "good government."

The fourth term of the series, Phaos, represents an orbital node in which planetary revolution would be synchronous with two planetary revolutions at Sun's surface.

The fifth term of the series, Lychnis, represents an orbital node at which Herschel's theoretical "subsidence" would give Sun's present velocity of rotation.

The sixth term of the series represents a node which is somewhat within Sun's apparent surface, or at its actual surface, provided the depth of the photosphere is one per cent. of Sun's radius.

The one hundred and eighty-seventh term of the first series represents an orbital node at the upper surface of Sun's photosphere. Its harmonic denominator represents the ratio of Sun's mass to the aggregate planetary mass.

We see, therefore, in the second series, not only the nodal influence of the largest two bodies in the system, Sun and Jupiter, but also an accordant influence of our own planet, which is the central orb and the largest planet in the belt which is bounded by the secular perihelion of Mercury and the secular aphelion of Mars.

Herschel's modified presentation of the nebular hypothesis furnishes the needful grounds for a satisfactory explanation of such remarkable velocities as that of the inner moon of Mars. It also seems to require that secondary orbs, when they revolve in less time than is required for the rotation of their primaries, should be denser than the primaries. There is, therefore, good reason for the further prediction that, whenever the density of Phobos is ascertained, it will be found to be greater than that of the planet itself. If Mars has any other moons which have an orbital period of less than twenty-four hours, they should also be of like superior density. In these harmonies, as well as in many others, the pointing to the primeval organizing agency of light is interesting and suggestive. At the theoretical period of each of the harmonic divisions, and at all other stages of nebular condensation, the rhythmical rotation of our day-star has been repeating its unvarying confirmation of the old, old record. In the dim and distant past, in the living present, and through all coming time; from the great "Beginning," until the culmination of prophecy when "the elements shall melt with fervent heat;" nothing but Divine intervention has disturbed, or can disturb, the equality between the accumulated action of solar gravity for a half-rotation and the velocity of light. The harmonic hypothesis forecasts the same requirement, at the surface of the central orb in every stellar system, so that the closing refrain in the hymn of each of the morning stars, is, was, and ever shall be:

"And God said, Let there be light; and there was light."

# NOTE ON THE POWER OF WATER TO HOLD MATTER IN SUSPENSION.

By CLEMENS HERSCHEL, C. E., of Boston, Mass.

I desire to offer a few remarks, partly in answer to Mr. Frizell's note, in the September number of this JOURNAL, and partly in extension of my own paper, in the numbers for May, June and July. Says Mr. Frizell, criticising M. Dupuit's Theory: "Force or pressure is *tendency to produce motion*. There can be no unbalanced pressure in a mass of water without a corresponding motion. Yet the theory only contemplates a horizontal movement from *A* towards *B*."

It is not, perhaps, my part to defend the theories of M. Dupuit, but it may be of interest to the readers of this JOURNAL for me to say that I do not read M. Dupuit in the way Mr. Frizell does. I think M. Dupuit not only contemplates, but says he has observed, the *motion* at right angles to the general flow of the stream, produced by the unbalanced pressure of contiguous filaments of water. In speaking of their *upward* pressure, as suspending solid matter, he compares it to the lateral pressure which draws a floating body from the shore into the thread of the current. This, certainly, is a case of *motion* caused by unbalanced pressure laterally.

Says Mr. Frizell, a little further on: "A solid particle heavier than water, and suspended therein, never ceases to sink with the full velocity determined by its size and specific gravity." And Mr. Frizell has clearly shown how a body of 1 ft. diameter, will sink at the rate of 9·17 ft. per second, when diameters of ·01 ft. and of 0·000000000229 ft. will sink at the rates, only, of 0·917 ft. per second, and 6 in. per hour, respectively. But let us suppose a vertical velocity in the water of only 0·918 ft. per second, and of 6·1 in. per hour, and the bodies named will at once cease to sink, and will begin, instead, to rise. It is a precisely analagous case to Mr. Frizell's clever method for compressing air. Bubbles of air, it might have been said, never cease to rise; but Mr. Frizell has shown us, that when enclosed in water moving at a proper velocity, they are carried downwards and are compressed. Similarly, the particles of clay, and even gravel stones, though ordinarily never ceasing to fall, are made to rise by an upward current of water.

That such upward currents actually exist, may be clearly proven. While I have been delaying the writing of this much of this note, Mr. James B. Francis, Engineer of the Proprietors of Locks and Canals on Merrimack River, has published, in the Transactions of the American Society of Civil Engineers, the results of experiments made by him years ago, in which this vertical velocity of the water could be observed, and in a number just issued he calls attention to the fact that herein lies the explanation of the power of water to hold matter in suspension. Again, a German engineer, Mr. Harder, has recently published a new theory of the movement of water in rivers and canals, in which it is shown by *analytical* reasoning and calculation, that the lower layers of water are constantly rising to the surface, even in the case of water flowing uniformly. The fact is, that the theories of water flowing in rivers and canals, which suppose only a horizontal movement of the particles moved, are every one of them based on a snare and a delusion, and it is probable that they will be universally modified or abandoned before very long.

I desire, in conclusion, to offer some suggestions as to how experimental proof, and measurement as well, of the vertical motion of flowing water could be obtained. A properly constructed current-meter will measure the component of the velocity of the water in line with its axis of rotation. It will measure velocities as low as 0·15 ft. per second, and I think can be made to measure as low as 0·10 ft. per second, holding the instrument in one spot. But by moving the meter with a known and uniform velocity, first with the current to be measured, and then against it, I have measured a velocity of only 0·02 ft. per second. Working in this way, the vertical component of the velocity could readily be ascertained; likewise the horizontal velocity, and, from the two, the velocity in any other intermediate line. Also, the *lateral* velocity, spoken of by M. Dupuit. I do not go into the details of this matter now, as I am preparing an account of a series of experiments made with current-meters at Lowell, Mass. They extended over two seasons, and were made with a perfection of apparatus not always at the service of experimenters. This account, it is expected, will be ready for publication in a few months.

Boston, *October* 16*th*, 1878.

# ON THE COMPUTATION OF TABLES OF WEIGHTS OR VALUES OF MACHINERY OR MACHINE DETAILS.

By Robt. Briggs, C. E.

The preparation of tabular statements of the weights or the cost of details of machinery, or of machines completed as a whole, to be used as reference tables in construction, or for manufacturing or sales values, is one of the most onerous demands on the skill of the mechanical engineer.

Generally but few examples of any especial form of detail or machine are drawn out fully, or put in proper shape to be estimated upon, but even where the whole list of a number of separate sizes of details or machines are worked up, and even also when actual weights and costs are made out, there will appear discrepant results which demand to be reconciled by sound judgment, in comparisons of values, to give reliable data for future use.

The common method of correcting values is the graphic one. On a scale, where a line of abscissæ is divided to express the linear dimension (diameter or side of cube), are erected ordinates, in terms of numerical weights or values, for as many sizes as may be computed out; when the smoothness of the curve delineated by the ordinates indicates the precision of the estimates, and the corrected curve which passes nearest to several quantities or values admits of the interpolation of other ordinates, thus serving to complete the table without calling for further estimates. That these curves are expressed by some equation in the form of $C + aD + bD^2 + cD^3 + \ldots\ldots$ is easily demonstrable and may be admitted, but the seeking for such an equation involves far more trouble than the graphic method alluded to, so that the method by equation may be set aside as impracticable. But, on the other hand, it is not as generally known that by the adoption of one of the properties of the equation, a ready mode is offered of approximating to the desired values and of correcting the accidental discrepancies of weights or of costs of work. The method of successive differences of ascertained values is more easily applied in most instances than the graphic one, and it is theoretically accurate. The demonstration of this last fact is entirely elementary. Thus, if the equation is that of a straight line, or $C + aD$, it is evident that in the

first difference of a series of values, $C$, which is the constant, will disappear, and the result will be $aD$; $a(D+1)$; $a(D+2)$; $a(D+3)$, etc. The supposition being that $D$ increases 1 unit in each case in forming the table—from whence the second differences become $a$, $2a$, $3a$, etc., as $a\,D$ disappears in this case. The next difference becomes $a$ only for each value, and the next again zero. If the equation has the form $C + aD \times bD^2$ one more successive difference will remove all the figures and become zero. It consequently follows that if we can ascertain the value of the constant of the first, second or third, or other constant difference, we can establish an accurate table of values within the limits of our examples accepted as data. Noting that for the determination of the formula $C + aD$, we must have two values, for that of $C + aD + bD^2$, three values; for that of $C + aD + bD^2 + cD^3$, four values, etc.

A numerical example of this proposition may not be out of place:

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| For $D=$ | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| let $C=$ | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| 1st difference, | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| For $D=$ | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| let $a=5.\therefore aD=$ | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
| 1st difference, | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | |
| 2d difference, | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $C+aD=$ | 9 | 14 | 19 | 24 | 29 | 34 | 39 | 44 | 49 | 54 |
| 1st difference, | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | |
| 2d difference, | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| For $D=$ | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| $D^2=$ | 1 | 4 | 9 | 16 | 25 | 36 | 49 | 64 | 81 | 100 |
| let $b=3.\therefore bD^2=$ | 3 | 12 | 27 | 48 | 75 | 108 | 147 | 192 | 243 | 300 |
| 1st difference, | 9 | 15 | 21 | 27 | 33 | 39 | 45 | 51 | 57 | |
| 2d difference, | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | | |
| 3d difference, | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $C+aD+bD^2=$ | 12 | 26 | 46 | 72 | 104 | 142 | 186 | 236 | 292 | 354 |
| 1st difference, | 14 | 20 | 26 | 32 | 38 | 44 | 56 | 56 | 62 | |
| 2d difference, | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | | |
| 3d difference, | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | |

I will not pursue this to the cubic value of $D$, but it is evident that whatever power be taken, somewhere the successive differences will end in zero, regardless of any particular value for $C$, $a$, $b$, $c$ or $D$ which may be taken.

Take for instance cast-iron water-pipes, referring to their internal diameters as the units of dimension. To suit the conditions of strength simply, the thickness of such pipes can be held to vary as the diameters, but to satisfy the requirement for moulding, especially in lengths which are the same for all diameters (of pipes from 4 inches to 20 inches), and of running of the molten iron, some constant of thickness will appear, which will express the theoretic least thickness when the diameter becomes zero, but which, for practical use, is a larger part of the material in the smaller pipes. The formula for thickness thus becomes, $T = C + aD$, which is the expression for a straight line where $a$ is a coefficient determined by the required strength of the pipe as related to the strength of material employed; $D$ is any diameter of a particular pipe in inches (or other units) and $C$ is the constant of thickness also in inches. The weight of a foot (or other unit) of length of such a pipe, with its thickness corresponding to this formula will of course be $= k\,[(D + 2\,T)^2 - D^2]$, where $k$ is a coefficient expressing the weight of one inch round of the cast-iron one foot in length. This formula reduces to $= k\,[(a^2 + a)\,D^2 + (2\,aC + C)\,D + C^2]$ and becomes simply $= C + aD + bD^2$ with especial values for $a$ and $b$. This curve can be tabulated by differences, after computing any three values of the series. If the cast-iron pipes were plain cylinders without bell or flange ends, all of the same lengths, then the weights of the several sizes would be found by the same formula; but the bells or flanges will be found to bear a relation to the length, as the *diameter of the pipes multiplied by same coefficient plus a constant* and the final cubic values of material in pipes either bell or flanged, or their weight, will vary as $C + aD + bD^2 + cD^3$. This system demands three accurate examples for its solution, and the fourth successive difference is zero. Again, the value of the cast-iron in the pipes does not follow the weight of the iron in each piece. Difficulties of moulding and cost of handling the material cause an increase of worth of the metal in the larger pieces on the one hand if they are relatively light, or in the smaller pieces on the other if the number of pieces to be made become large, so that another ratio of $C + aD$ may be needful to introduce, where either $a$ or $C$ may be plus or minus quantities. If this last proposition does not apply fully to the cost of cast-iron pipes, it does so decidedly for general machine-castings and machine work, so that the most used formula for a long range of values may be considered to be $C + aD + bD^2$

$+ c D^3 + e D^4$ and the fifth difference, usually a very small one indeed, is required to reconcile a set of closely-made estimates. The great excellence of the method here advanced is, that a slight examination of the conditions will allow the computer to see what order of differences are needful to give a correct result, and if the computed examples do not conform to a curve of the proper order, he can correct them without re-estimating.

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## ON FURTHER APPLICATIONS OF THE FLOW OF SOLIDS.

By M. Henri Tresca, President of the Societé des Ingénieurs Civiles, Paris.

(Continued from Vol. lxxvi, page 270.)

Iron, by its constitution, lends itself much better to drawing out than to setting-up. The difference is well exemplified in the case of a wagon axle which has been bent while cold. If it be divided down the centre in a plane, the fine ribbon-like appearance is clearly brought out, and the lines are very exactly concentric. In the convex portion, it might be believed that the lines were described with compasses. In the concave portion, on the contrary, the fibres are broken and confused; at the same time, there are two fractures by compression, whilst the exterior face remains entire. Here the texture would have been altered to a still greater extent, if the iron had been heated for the operation, when the metal would have been brought to a consistency like that of putty.

The deformations transversely are much better shown in a square axle 4 inches square, the surface of which had been subjected to a series of blows from a centre-punch, at intervals of 0·4 inches. The convex portion has been extended so much that the width has been reduced from 4 inches to 3·20 inches, and the concave has, on the contrary, been spread out to a width of 5½ inches, in proportion as it was shortened in length. The simultaneousness of such deformations is well known, and they are the more pronounced as the curvature is increased. But it is specially important to note, in this example, that the fissures which are produced are situated only in the compressed portion, whilst the portion principally submitted to extension has continued perfectly sound.

For the purpose of testing the soundness of the welds in rails the rails are frequently subjected to a series of torsional stresses in two opposite directions, which usually result in a number of longitudinal fissures of greater or less length, in the lines of separation of the component bars. But, in operating on a shaft turned out of a square bar of good iron, much more conclusive results are obtained. By the application of excessive torsional stress, the fibres are forced into relief, and the iron shaft absolutely assumes the form of a rope, in which all the exterior fibres are apparent. But the constitution of the interior of the shaft is still more remarkable. If a transverse section be taken it is easy to discover, by the agency of oxidation, the sinuous lines which correspond to the exterior helices, and of which the equation is precisely given by calculation, assuming that the angle of torsion is constant for all points of the shaft.

Supposing such a piece were to be raised to a welding heat and forged anew, it can scarcely be doubted that an iron of exceptionally great resisting power would be produced, possessing in some degree the best properties of metallic cables.

The ribbon-like constitution is never better manifested than in iron plates, in which it might often serve to reveal the mode of manufacture. In iron tubes, for example, which are manufactured mostly in England and in France, the regularity of the lines is such that it is only interrupted at the weld; and a means is afforded for ascertaining whether the weld has been made by simple contact, or by lapping.

The same manufacture demonstrates also the inconveniences which may attend compression. In the section of a nut for an iron tube, it is made evident by the mode of striation that the hexagonal form is produced by drawing out from a circular section, outside as well as inside. The layers are, at some points, separated towards the angles, where it was necessary that the section should be enlarged by squeezing or compression.

The object to be kept in view in the various methods of forging should be, according to the foregoing discussion, to dispose the fibres in the direction which best accords with the use to which the piece is to be applied. Mr. Haswell, director of the workshops of the Southern Railway at Vienna, has attained this object by stamping in dies piles which are suitably prepared. The author has had oxidized several of the pieces manufactured by this process for rail-

way service; and it is clearly manifest that, though, here and there, the silicates occupy too much space, and are not regularly diffused, the fibres are nevertheless arranged in the most favorable direction in all parts of the section.

At several other iron works, the example of Mr. Haswell has been followed, in the manufacture of pieces by stamping, particularly at the iron works of Niederbronn. But no doubt iron of the best quality should be employed, in order to derive from this method of manufacture all the advantages which it promises.

The defects of the system are well exhibited in the section of a key, forged by the stamping process from a bar of iron doubled twice over on itself.

In all operations to which iron is to be submitted it is important that the particular form of its constitution should be regarded. The excellent iron plates of Berry, which may be easily doubled, because their different layers are not sufficiently susceptible of being welded, could not, for instance, be subjected to the American mode of punching, with a punch which, being faced with a helicoid surface instead of the usual flat surface, manifestly tends to tear, at the edges of the hole, the different parts of the same layer.

*Heat Developed in Forging.*—The study, geometrically, of the deformations produced by forging considered under the simplest conditions, has led, from another point of view, to results which, though they are not translated into definite figures, are nevertheless of some interest, whether having regard to the deformations themselves, or to the calorific phenomena by which they are accompanied.

When a square bar of iron is compressed between two horizontal flat jaws, equal and opposite to each other, the bar is flattened and elongated, and the experiments already made on the crushing of metal disks afford grounds for believing that each vertical fibre of molecules is deflected into a sinuous form, analogous to the forms produced by the crushing of a cylindrical block consisting of a pile of plates. When a prism is partially flattened the flow of the material placed under the tool is resolved into an elongation having a curved surface, which the directrix is a logarithmic curve. The equation of the curve might be given, but it is useless to enter here into theoretical speculations. It will suffice, meantime, to mention the result, and to apply it where necessary in the course of the discussion.

In a special example of deformation obtained on a bar of lead by the blow of a hammer, the distortion very much resembles those which have been already illustrated.

If each of the four faces of the prism be divided into squares of one centimetre, or 0·40 inches wide, the comparison of the figures will show all the changes which take place on one of the sides. A small enlargement of 0·12 inches is produced on the upper face and the lower face, but this may be neglected at first. Towards the middle of the depressed portion the intermediate horizontal lines present their convexity in contrary directions towards the centre-line; and the two verticals near the centre vertical have on the contrary their maximum separation from each other at the level of the centre.

The two opposite squares, having a width of 0·12 inches, show respectively two symmetrical depressions; but it is the four squares formed by the diagonals which manifest the most complicated distortions. In proportion to the depression produced, the subjacent matter is expelled both transversely and longitudinally; but the second displacement is that which it is most important to take into consideration, with respect to the elongation to be produced, and it is the only displacement which can take place, when the piece is forged by stamping.

The elongation in the interior of the compressed portion being gradual, the depressed edge resulting from it necessarily presents an inclined face. It would theoretically take a logarithmic form, of which the curve would unite nearly at right angles with the original face above, which is displaced longitudinally, and, at the bottom of the depression, with the depressed portion of the same original face. This exterior side of each of the original faces of the square is thus drawn into a form analogous to that of a letter Z, of which the inclined member has been bent over in the opposite direction. The three other sides, elongated or shortened, constitute the locality of the greatest deformations; and it is to this to which the whole attention should be directed. The original lines, as well as the resulting deformations of these lines, are illustrated with absolute exactness by a figure.

It is thus shown what takes places under the action of the first blow of the hammer. The second blow should cross the first blow, when it is required to reduce the height for the whole length of the

bar; and an idea may be formed of the new deformations and the re-straightenings which take place, by examining the figures, in which the dividing lines are reproduced after each of three or four successive blows, one after the other. In spite of the care which was taken, the deformations are not sufficiently symmetrical, but they are characteristic enough to remove any doubt as to the distribution of the molecular action to which every part of the mass has been submitted.

The forged bar presents extended portions, and compressed portions, and the result of the work would evidently be the best possible if the vertical lines, successively deformed in two different directions, resumed a rectilinear arrangement after each deviation. The forging would then consist of a methodical series of the effects of deformation, immediately followed by the effects of a corresponding rectification.

Such effects become still more complex when the bar to be forged is not sustained between lateral guides by which all lateral extension is prevented. It is evident that new deformations will be presented under such conditions, which will modify those which have just been analyzed, and attention should be directed more particularly to the semi-circular protuberances which are distributed over the length of the piece, in correspondence with each blow of the hammer. These nipples form a kind of network produced by the forging, describing on the lateral surface a series of lozenges with curved sides, separated by the half circles already mentioned.

These undulations of the surface, which are of no importance in the geometrical operation of forging, nevertheless deserve notice, as they indicate the zones of maximum sliding, which are also the zones of the maximum development of heat; and the author has been enabled, by their indications, to connect the phenomena of forging with those of thermodynamics. It has long been known that heat is developed by the forging of a metal, and in some operations connected with the *platinage* of steel, pieces of steel subjected to blows rapidly delivered, may be raised to a dark-red heat. This phenomena does not ordinarily take place, except in working thin sheets; and it will be shown that, in working thicker pieces, the precise situation of the greatest development of heat can be recognized.

In a forging operation which the author has had to conduct on a large scale on an alloy of iridium with platinum, a phenomenon

occurred incidentally which engrossed his whole attention, bearing intimately as it did on the deformation of solid bodies. He may be permitted to refer to it, though the experiments are not yet completed; and it will be a source of great satisfaction to him to make known the first results of these experiments to an assembly of English engineers before any publication of them elsewhere.

On the 8th of June, 1874, the author simply announced the main fact at the Academy of Sciences, that when the bar of platinum, after having been forged, had cooled to a temperature below that of red heat, it happened several times that the blows of the steam-hammer which at the same time made a local depression in the bar and lengthened it, also reheated the bar in the direction of two lines inclined to each other, forming on the sides of the piece the two diagonals of the depressed part; and this reheating was such that the metal was in these lines fully restored to a red heat, so that the form of these luminous zones could be clearly distinguished. These lines of augmented heat remained luminous for some seconds, and presented the appearance of the two limbs of the letter X. Under certain conditions as many as six of these produced successively could be counted simultaneously, following one another according as the piece was lifted under the hammer so as to be gradually drawn down for a certain part of its length.

The appearance of these luminous traces can be explained beyond all doubt. They were the lines of greatest sliding, and also the zones of the greatest development of heat—a perfectly definite manifestation of the principles of thermodynamics. That the fact had not been observed before was evidently owing to this, that the conditions necessary to be combined at the same moment had not been present under such favorable circumstances. Iridized platinum requires for its deformation a large quantity of work to be expended upon it. The surface takes no scale, and is almost translucid when the metal is brought up to a red heat. The metal is but an indifferent conductor of heat, and its specific heat is low. All these are conditions which are favorable for rendering the phenomena visible in the forging of this metal, whilst it has remained unobserved with all others.

Although this explanation was what was to be expected, the author nevertheless proceeded to justify it by experiments of a more direct character, of which some account will now be given; and which

constitute the chief motive, and it may be added the chief point of interest in this communication.

Given a bar of metal at the ordinary temperature, if, after having coated it with wax or with tallow on two faces, it be subjected to a single blow of the steam-hammer, the wax melts where the depression is produced, and it is observed that the melted wax assumes in certain cases the form of the letter X, as was observed in the case of the platinum bar. In other cases the limbs of the cross are curved, presenting their convex sides to each other. The heat has then been more widely disseminated, and the wax melted over the whole of the interval by which the curves are separated.

The prism which has this melted outline for base, and for height the width of the bar, represents a certain volume and a certain weight; and if it be admitted that the whole piece has been raised to the temperature of the melted wax, the elevation of temperature represents a certain quantity of heat, or, in the ratio of the mechanical equivalent, a certain quantity of internal work which is directly exhibited by the experiment. In comparing this work with the work done by the fall of the hammer, a coefficient of efficiency is obtained which amounts to not less than 70 per cent. This value cannot be taken as final; it depends upon the conductibility of the metal, on the stiffness of the apparatus, on the clearness of outline of the melted surface. But what the author is desirous to impress upon the meeting is that here there is a return to the first methods of Mr. Joule, and that the author's investigations of the flow of solids conduct him to certain thermodynamic demonstrations.

The following are the numerical data for some of these experiments, together with the illustrative figures:

| Name of Metal. | Work of the Ram. | Form of the Impression. | Area of Wax melted. | Thickness of the forging. |
|---|---|---|---|---|
| | kgm. | | sq. cent. | cent. |
| Iron, . . . . | 80 | Rectangular. | 1·65 | 2·5 |
| " . . . . | 90 | " | 1·50 | 2·5 |
| " . . . . | 110 | Wide-spreading. | 2·20 | 2·5 |
| Copper, . . . . | 60 | Rectangular. | 1·75 | 2·0 |

| Volume of the corresponding prism. | Corresponding number of heat-units (heating to 50 deg. C.) | Equivalent work at the rate of 435 kgm. per calorie. | Proportion percentage of total work converted into heat. |
|---|---|---|---|
| cub. cent. | | kgm. | |
| 3·63 | 0·1498 | 63·72 | 0·796 |
| 3·75 | 0·1544 | 69·79 | 0·731 |
| 5·50 | 0·2269 | 96·44 | 0·877 |
| 3·50 | 0·1329 | 56·48 | 0·942 |

In the last experiment, taking as melted the area of wax included between the hammer and the crosses, a useful effect of 94 per cent. is obtained.

*Stamping.*—The object of stamping is to dispose the relative displacement in given directions, in order to pass from the primitive form, supplied direct by the maker, to the definitive form, which is desired to be accomplished. From this point of view, the die is a kind of channel designed to facilitate the flow of the material, and to guide in the most suitable direction or directions.

When it is required to draw down by stamping a square bar of iron, each blow of the hammer causes transverse enlargement as well as elongation; and the useless enlargement is advantageously obviated if it be prevented by the presence of the sides of the canal. If it be well to employ the stamp in simply drawing down a bar, how much more indispensable is it when the variation of form is more complex? The simple idea of flow supplies material for forming a rational judgment on the successive dispositions of the stamps required for the intermediate operations; and also on the adjustment of the sections of rolls, which are but circular stamps or moulds, by means of which iron is drawn out.

That all these phenomena are but various forms of flow, of which in most cases the circumstances can be anticipated, may be shown by other experiments which will now be described.

The most characteristic of these experiments is, perhaps, the following: Having completely effaced the reverse in relief of a piece of money, place the flat surface on a sheet of lead, and flatten the second face in the stamping press. The whole relief of this face will

be produced on the face which had been reduced to flatness; and the design of this relief will even be imprinted on the lead. This effect is explained by the circumstance that each vertical thread or fibre of molecules, being separately compressed in the direction of its length, flows, when struck, with greater facility into the lead than into the other parts of the piece. The saliencies, as reproduced, are less, no doubt, than in the original relief, whilst the more delicate features are partially obliterated, but the general effect is reproduced, and it is apparent that the flow takes place in the direction of the depth, which is also the direction of least resistance.

On the reverse of the sheet of lead, which has necessarily been reduced in thickness by the effect of the imprint, the image will be found repeated in a more confused manner, and it may be distinguished by a peculiar tint, which indicates a well-defined geometrical transformation; the lead having flowed in a horizontal direction, as the only way of escape when its surface was depressed. This amplification or enlargement takes place in the proportion of 22 to 13, when the plate of lead is $\frac{1}{8}$ inch thick.

[To be continued ]

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## MEMOIRS ON THE LIQUEFACTION OF OXYGEN, THE LIQUEFACTION AND SOLIDIFICATION OF HYDROGEN, AND ON THE THEORIES OF THE CHANGES IN CONDITION OF BODIES.

By R. Pictet.

[Continued from Vol. lxxvi, page 239.]

### V.—Liquefaction and Solidification of Hydrogen.

After having obtained the foregoing results with oxygen gas, we were naturally led to treat hydrogen in the same manner. The entire mechanical apparatus used for the first gas could be used for the second without alteration.

It was merely necessary to decide upon a thoroughly understood chemical method of generating "pure hydrogen," without water and without a trace of a foreign gas, and at the same time leaving a "non-volatile residue" in the flask. These two conditions are indispensable if we desire to proceed with any accuracy, and do not wish

to complicate the indications of the experiment by introducing factors whose influence it is impossible to measure. For this reason I rejected the methods depending on the decomposition of water, either by means of the alkaline metals or the pile; and I adopted the following method, by the advice of Professor Monnier.

M. Berthelot, Professor at Paris, in a synthesis of oxalic acid and formic acid, has shown that if formate of potassa be mixed with caustic potassa, and heated to 225°, absolutely pure hydrogen is obtained, without any trace of water, or of a foreign substance. The following is the formula which explains the reaction:

$$4\ CHO^2K + 2\ KHO = C^2O^4K^2 + 2\ CO^3K^2 + H^6.$$

Adding an excess of potassa, the following reaction takes place:

$$C^2O^4K^2 + 2\ KHO = 2\ CO^3K^2 + H^2.$$

Total hydrogen, $H^8$.

The residue consists solely of carbonate of potassa, which remains in the flask and is not volatile.

The preliminary experiments made in the laboratory gave very satisfactory results. The reaction progresses unintermittently and the temperature remains stationary at 225°.

The following is the charge of formate of potassa and potassa we placed in the flask for the first experiment, made on Thursday, Jan. 10th, from 7 to 9 o'clock P. M.

Formate, $CHO^2K = 1261$ grammes.
Potassa, $KHO = 500$ grammes.

The whole was previously heated to 150°, to drive off every trace of water and to afford absolute certainty of the purity of the mixture. The flask itself was heated to 150° to avoid the influence of humidity in every possible manner. These preparations accomplished, the flask was secured in its place and the operation commenced.

The sulphurous acid pumps condensed the protoxide of nitrogen regularly as in the preceding experiments, and soon a thick hoar frost appearing on the oxygen manometer, indicated that we might hasten the liberation of the hydrogen.

The following are my notes, taken during the experiment:

8.32 o'clock.—The hoar frost is very heavy, especially on the pipes conducting the protoxide of nitrogen. The pressure of the hydrogen is 50 atmospheres.

| | | | | |
|---|---|---|---|---|
| 8.34 | P. M. | Pressure | 60 | atmospheres. |
| 8.35 | " | " | 70 | " |
| 8.38 | " | " | 80 | " |
| 8.43 | " | " | 90 | " |
| 8.45 | " | " | 92 | " |

The gas flame is slightly lowered, so as not to overheat the outside of the flask, and to equalize the temperature.

| | | | | |
|---|---|---|---|---|
| 8.47 | P. M. | Pressure | 100 | atmospheres. |
| 8.50 | " | " | 112 | " |
| 8.52 | " | " | 120 | " |
| 8.54 | " | " | 140 | " |
| 8.56 | " | " | 150 | " |
| 8.58 | " | " | 170 | " |
| 8.59 | " | " | 190 | " |
| 9.00 | " | " | 200 | " |
| 9.01 | " | " | 215 | " |
| 9.01.30 | " | " | 225 | " |
| 9.01.45 | " | " | 240 | " |
| 9.02 | " | " | 260 | " |
| 9·04 | " | " | 300 | " |
| 9.05 | " | " | 340 | " |
| 9.05.30 | " | " | 350 | " |
| 9.06 | " | " | 370 | " |
| 9.06.15 | " | " | 400 | " |
| 9.06.30 | " | " | 450 | " |
| 9.07 | " | " | 500 | " |
| 9.08 | " | " | 550 | " |
| 9.09 | " | " | 590 | " |
| 9.10.30 | " | " | 640 | " |
| 9.11 | " | " | 650 | " |
| 9.11.30 | " | " | 652 | " |

The pressure is almost stationary after having gradually risen during 40 minutes, I open the plug-cock.

The jet is illuminated by a strong electric light.

At the moment of opening, an opaque jet of a well-defined steel-blue tint is seen to issue from the orifice. The opaque portion is about 14 centimetres in length and 15 to 20 millimetres in diameter. Below this blue non-transparent part, and through a dense mist, produced by the vesicular condensation of the hydrogen, a whitish zone might be clearly distinguished, of a lighter blue than that of which it was the continuation, and sufficiently translucent to allow the strongly illuminated objects on the opposite side to be distinguished.

At the same moment we heard a sharp hissing noise, similar to that produced by a red-hot bar of iron plunged suddenly into water; then simultaneously a pattering sound on the ground, similar to that caused by grain falling on the earth.

The jet, instead of remaining continuous, as was the case with the oxygen, became intermittent, only escaping spasmodically.

Every expulsion was accompanied by the same crackling we just mentioned. After several seconds, I closed the regulating cock; the pressure was still at 370 atmospheres. This pressure dropped gradually to 320 atmospheres, then rose slowly and during several minutes to 330 atmospheres. At 9.18, I reopened the stop-cock.

An extremely short jet issued, with a violent expulsion of solid corpuscules; then, though the orifice was still left open, nothing passed out. The manometer indicated 315 atmospheres.

Seeing this entire stoppage in the ejection of the hydrogen, we immediately concluded that its solidification, in the interior of the tube, had been accomplished. So as to assure ourselves, I had the pumps which exhausted the vapors of protoxide of nitrogen stopped, and I opened the regulating-cock, so as to produce a condensation of the vapors of the protoxide of nitrogen in tube *D*.

This *manœuvre* having caused the temperature to rise, the ejection of the hydrogen recommenced in an intermittent manner, by discharges which became more and more frequent. They followed each other at half-minute intervals, retaining the described appearance. About a quarter of an hour after opening the regulating-cock, the last discharge took place, and the pressure returned to *O*.

Towards the close of the experiment we were able to ignite the gas issuing between the discharges, but at each violent ejection the flame was extinguished.

This first research affords no clue to the density of liquid or solid hydrogen, as the observations gave us no exact figures concerning the quantity of hydrogen contained in the tube at each moment. The intermission between the discharges, the partial or total congelation of the liquid hydrogen, the variations of the manometer, all these violent unforeseen disturbances entirely disarranged our observations, and we shall be obliged to recommence them with great care to obtain some conclusive figures.

Nevertheless, this experiment allows us to assume that it is possible to liquefy hydrogen under a pressure of 650 atmospheres at —140°.

This pressure in every case exceeds that of the maximum tension of the vapors of hydrogen, corresponding to —140°.

As regards the "solidification of hydrogen," it could not only have been foreseen, but even predicted on account of the light atomic weight of the body.

The latent heats of liquids are known to be appreciably in an inverse ratio to the atomic weights of their vapors. The exact formula, giving the latent heat, is as we have demonstrated it:

$$\lambda = \frac{10333\,(274 + t) \times 0{\cdot}041}{1{\cdot}293\,\delta \times 431}.$$

in which $\delta$ corresponds to limit of density; that is, to the atomic weight.

$t$ is the temperature of ebullition.

If we now apply this formula to liquid oxygen and hydrogen, it will be seen that the values of $\lambda$ for each liquid should be nearly in the same ratio as the atomic weights.

In fact, these two liquids have been obtained at the same temperature of —140° under pressures not varying much from each other. The temperatures of ebullition for each of those two bodies should not be more than 20° to 25° apart, at the most.

Designating the latent heat of oxygen by $\lambda$ and that of hydrogen by $\lambda'$, we should have the ratio

$$\frac{\lambda'}{\lambda} = \frac{(274 + t')\,\alpha}{(274 \times t)'\,\alpha'}$$

$274 + t'$ corresponds to the absolute temperature of hydrogen at the point of ebullition, and $274 + t$ is the absolute temperature of oxygen at the point of ebullition.

The atomic weights are to each other as $\frac{\alpha}{\alpha'} = 16$.

It is consequently "very probable" that the ratio of the latent heats will be:

$$\frac{\lambda'}{\lambda} = \frac{(274 + t')\,\alpha}{(274 + t)\,\alpha'} > 10$$

that is: the latent heat of hydrogen is at least ten times greater than that of oxygen.

If this hypothesis be correct, as soon as the condensed liquid can again evaporate, the quantity of heat absorbed by this change of condition is so considerable that the remaining liquid is constrained to solidify by congelation.

Starting from the ratio of the atomic weights, a kilogramme of condensed hydrogen should absorb more than 2000 calorics. There is no cause for surprise, that the experiment has confirmed what thermal equations indicated as very probable, and this verification is another proof sustaining the basis on which the mechanical theory of heat is founded.

We will soon commence new experiments on the liquefaction of hydrogen, and will endeavor to collect the products of condensation so as to investigate them more thoroughly. In fact, it would be very useful to determine the physical appearance of this body which by every analogy is to be considered a metal, and which seems to have assumed that character in the experiment just related.

## VI.—Inferences.

We cannot conclude this memoir without enumerating briefly the inferences which may be drawn from these experiments on the liquefaction of the gases, and recalling to mind the very similar results very recently obtained by M. L. Cailletet at Paris.

We have endeavored to reconcile the principal phenomena, concerning the so-called permanent gases, with the law of Mariotte, the theory of M. Clausius, the experiments of M. Regnault, and with those of M. Natterer.

The apparent antagonism shown, by a hasty investigation, between the law of cohesion and the mechanical theory of heat, disappears entirely on the introduction of a new factor which is "the length of the calorific oscillation."

In the experiments of M. Natterer, given in a table in the first chapter, we see the pressures increase more rapidly than the law of Mariotte would indicate; is this solely caused by the dimensions of the atoms or molecules of the gases, as explained by Clausius?

Certainly not, for were this cause the only one, the difference should be inappreciable up to a high pressure, sufficient to force the molecules almost into contact; then it should suddenly become very great, caused by the impenetrability of matter.

On the contrary, we see this deviation from the law of the compressibility of gases gradually increase, but pass unintermittently from a value equal naught, to a high one for great pressures. This clearly indicates that Mariotte's law is strictly true for gases, "as long as the mean distance of the molecules from each other is still

greater than the length of the calorific oscillation corresponding to the temperature of the gas." As soon as this distance becomes equal to the length of oscillation, the pressure grows more rapidly than is indicated by Mariotte's law; as the caloric force now increases the pressure of the gas. If the gaseous volume be still compressed at this moment, we encounter an obstacle growing stronger and stronger as the calorific vibrations take place with an energy that no force can master.

Experiments made on the expansion of solids and liquids, prove that it exerts an energy greater than molecular cohesion. We thus arrive at a point in the compression of gases, where we find as powerful a resistance as that offered by liquids and solids.

We have said that the molecular force of cohesion must assume a certain value, $K$, so that the liquid condition might be produced. This value of $K$ is a function of the temperature, equal for all liquids.

We can easily account, physically, for the necessity of such a condition:

Imagine a gaseous volume at any pressure, and assume that liquefaction has commenced. What are the peculiar physical characteristics of the condition of this vapor and of its liquid?

The liquid would evidently possess a "greater density" than that of the vapor and its surface of contact, which unites them, might be seen. The increase in the density of vapor at the moment of condensation is a proof of the closer approach of the molecules; but before condensation, did these molecules not attract each other at all?

They undoubtedly did; at each impulse two molecules were united by their force of attraction, but the temperature and the calorific vibrations corresponding to this elementary work of condensation, disengaged them at once, and prevented the liquid state from becoming stable.

In fact, molecular cohesion operating in a similar manner throughout all parts of this gaseous mass, and nowheres "with sufficient energy to render the condensation stable;" the gas retains its gaseous form.

If the number of gaseous molecules be now increased, and the temperature lowered, the separation will take place immediately in the gaseous mass, and the liquid will be precipitated to the bottom of the receptacle. The power of attraction having increased, by the closer approach of the molecules, and by the diminution of the amplitude of the calorific oscillations; when two molecules will have been united

by cohesion, they will no longer find the dynamical elements necessary to escape from its influence, which will then become permanent. From this moment condensation takes place uninterruptedly, and the liquid accumulates at the bottom of the condenser.

Therefore, there is necessarily a "very sharply-defined limit" for any condensing gaseous matter. This limit corresponds to the "critical point," as it is now called. At the critical point, the molecular attraction is equal to $K$, a constant for all liquids at the same temperature.

The experiments described all tend to afford a positive proof of the fact, that liquids are forcibly led to the gaseous state, at a certain temperature, "whatever may be the pressure and the volume" to which they are limited.

By a very fortunate coincidence, most of the phenomena relating to the condensation of the permanent gases have been explained at Paris, at the same moment as at Geneva.

This coincidence has a double advantage, first to give a degree of absolute certainty to the phenomena themselves; then to prove that all the deductions logically drawn from the mechanical theory of heat are *completely* confirmed when transplanted from the domain of pure speculation to that of experimental physics.

By means of a most elegant and perfectly simple arrangement, M. Cailletet has furnished an indisputable proof of the liquefaction of the permanent gases. His experiments, previous to mine, are based solely on the thermal influence due to the expansion of the gases. They can be easily reproduced, and before a numerous audience.

In 1828, that is just fifty years ago, Professor D. Colladon, corresponding member of the Academy of Sciences, made numerous attempts, at Geneva, to liquefy the incoercible gases, especially atmospheric air. His apparatus, represented[1] on Plate III, was very similar to that of M. Cailletet. The following is a short description:

The pressure was produced by a hydraulic pump, transmitted through a nipple, $C\,c$, to the interior and upper part of a very strong hollow steel cylinder, $B$, partially filled with mercury. In cylinder $B$ was a glass tube, $T$, open at the lower end, but joined at the upper

[1] The principal parts of this old apparatus still exist, and have been kept for several years in the offices of the Société genevoise pour la construction des instruments de physique.

end to a second tube, $t'$, of thick glass, whose interior diameter was but 1·5 to 2 millimetres. The second tube protruded from the cylinder, $B$, traversing the elongated neck of cover, $A$, to which it was joined by gum-lake; it was afterwards bent in the flame of an enameler's lamp, and its curved extremity, $t'$, could be chilled to render liquefaction visible if it could be accomplished. The gases experimented upon filled the whole of tube $T$ at the beginning of the experiment.

Professor Colladon experimented with temperatures of — 30° and with pressures reaching 400 atmospheres, without obtaining any result. Unhappily, the dynamic theory of heat was not yet known; but for that, on opening the water-escape cock suddenly, liquefaction of the permanent gases would have been accomplished fifty years ago.

M. D. Colladon facilitated our work by his invaluable advice, and we here acknowledge our profound gratitude.

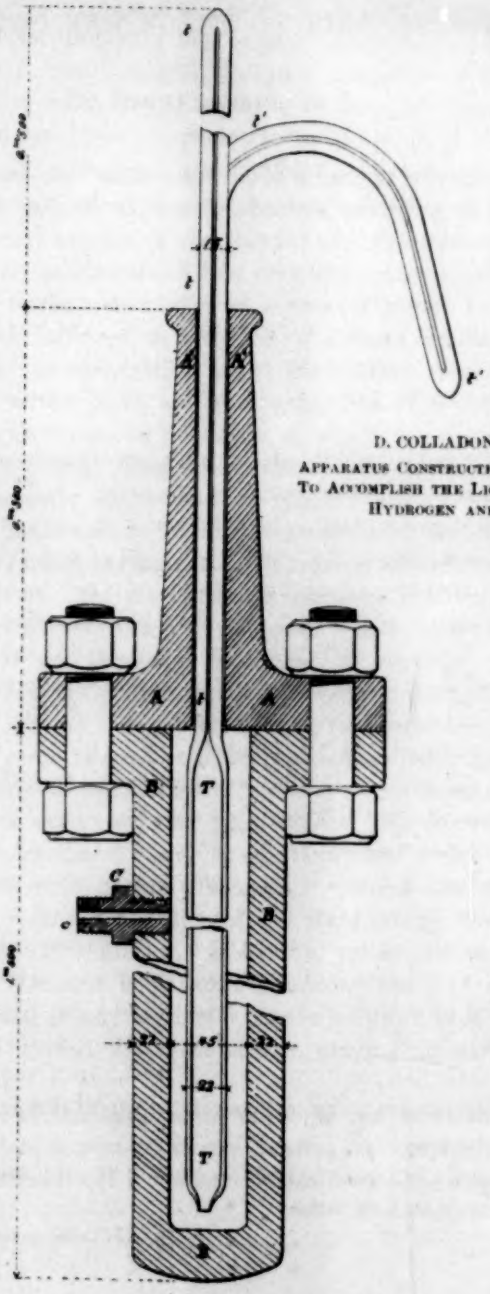
The investigation begun in this memoir requires numerous experiments for completion. A quantity of data of every description must be accumulated to give the numerical results perfect accuracy. What we desire, above all, is, that this class of researches will cause the employment of cold to be considered, in physical laboratories, as an essential means for the study of the molecular forces. Who knows but what crystallization and certain reactions may find peculiarly favorable conditions by this means?

One of the principal obstacles which have stopped the majority of experimentalists, is the want of mechanical aids, they being too expensive to be at the disposal of every one. Thanks to the "Society of Geneva for the construction of physical instruments," I had at my disposal a mechanical apparatus of great value and accuracy of workmanship, which might be valued at fifty thousand francs at least. It is solely due to this exceptionally advantageous circumstance, that I was enabled to succeed in these researches.

It is much to be desired that large laboratories should have similar means at their disposal; they would facilitate a thousand works of indisputable interest, which must now be abandoned for want of proper apparatus.

This memoir will be completed as soon as our experiments shall have furnished us with new data.

PICTET—PLATE III.




D. COLLADON, 1828.

APPARATUS CONSTRUCTED AT GENEVA, TO ACCOMPLISH THE LIQUEFACTION OF HYDROGEN AND AIR.

D. A. PARTRIDGE PHOTO-LITH. 9 S SEVENTH ST. PHILA

# NOTE ON TWO NEW FORMS OF BELL TELEPHONE.

By Brown Ayres, B. S.

The writer some time since constructed a form of telephone belonging to the third class of magneto-telephones, according to his classification in a former number of the Journal,[1] a description of which may be of interest as illustrating how very little, mechanically speaking, is essential to the transmission of articulate speech.

The instrument referred to consisted of a ferrotype plate, to the centre of which was connected a spiral steel spring, whose axis was at right angles to the plate, and the farther end of which was connected to an adjusting-screw by means of which the tension on the spring could be varied. This spring was of a fine piano-forte wire, and was permanently magnetized by rubbing with a bar-magnet. The spring and plate were in metallic connection, so that a complete circuit could be formed through the plate, spring, adjusting-screw and outside connections. On placing in the circuit a Bell Telephone of the modified form described in the paper before referred to, and speaking against the ferrotype membrane of our new telephone, words could be distinguished in the Bell Telephone, though they were not very loud. I have thought that under favorable circumstances this instrument could be used as a receiver, motion being imparted to the ferrotype-plate by the mutual attractions of the superposed portions of the helix when traversed by a current. In this event, however, the tone reproduced would be constantly one octave above the original tone, as both of the alternating currents would produce attractions, the retrograde motion of the plate arising from its own elasticity and that of the helix. I have not yet applied it, however, as a receiver. The same ends would be accomplished, of course, by the use of a spring of any conducting material which was traversed by a continuous current, the solenoid then playing the part of magnet and conductor.

Another form of the third class would be one in which we made the ferrotype-plate a portion of our circuit, the connections being made at the extremities of a diameter, and a horse-shoe magnet being

[1] Jour. Frank. Inst., June, 1878.

symmetrically placed with reference to this diameter in a plane through the centre at right angles to it.

In both these cases we have the simultaneous relative motion of magnet and conductor, and the form first described is interesting from the fact that the helical spring is at once the magnet and conductor.

BALTIMORE, *Oct.* 19, 1878.

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**The Part played by Coal-Dust in Producing Explosions in Mines.**—L. Simonin.—The author demands permission to make known certain facts which prove that it is in the majority of cases the heating of the coal-dust diffused in the galleries of the mines to which explosions are due. Referring to the catastrophe in the Jabin Mine at Saint Etienne (February 4th, 1877) he states, on the authority of the manager, that the mine in question contains very little fire-damp, and that the precautions hitherto taken with an exclusive reference to that gas are not sufficient. Others must be taken against the extremely fine coal-dust, which at the moment of the explosion of slight amounts of fire-damp, or even of blasting powder, liberates rapidly a part of the coal-gas which it contains, and propagates the explosion, reproducing the cause of the evil with so much the greater energy as the current of air is more violent. Thick crusts of coke (2 or 3 centimetres) prove this fact and explain how it is that extensive tracts in which fire-damp has never been observed are burnt like the rest of the workings. Hence, it appears that the precautions to be taken in fiery mines are complex whenever the coal-dust is rich in gas and very finely divided. Explosions may then ensue even in mines where fire-damp is unknown. There is no need to suggest the existence of cavities full of carbonic oxide, or of gaseous hydrocarbons, and suddenly laid open by a blow from the miner's pick. [Is not the attempt, recently made in some mines, to screen the coal below ground, a dangerous mistake as calculated to increase the quantity of dust diffused in the air of the mine?—*Ed. C. N.*]—*Chem. News.*

**Retention of Heat.**—MM. Blaugy, Poure & Co., manufacturers at Boulogne-sur-Mer, adopt the following plan to prevent the loss of heat in the steam-pipes, generator domes, machine cylinders, etc., of their workshops. They simply cover the surfaces with sawdust mixed

with flour paste. If the paste is very liquid, if the mixture is taken in the form of a stiff dough, and if the surfaces have been well cleaned from grease, the adhesion is perfect and free from cracks. They cover their apparatus with five successive layers of five millimetres each, or a total thickness of 25 millimetres (9·84 inches), which gives them a much better result than 50 millimetres of any of the other materials which are usually employed. The cost is almost nothing; with 50 kilogrammes (110·23 pounds) of farina at an expense of about 20 fr. ($5.00), they obtain the same result as with 1000 fr. ($200.00), expended for other materials. The paste is composed of farina, without the addition of starch. The mixture can be applied by a trowel with the greatest facility, either internally or externally. If there is much exposure, two or three coatings of coal-tar render it impermeable to water. If the tubes are of copper, two or three light coats of a hot liquid solution of clay should be first applied, in order to increase the adhesion of the sawdust.—*Les Mondes.* C.

**Acceleration of Nervous Velocity by the Will.**—Chauveau has lately undertaken two distinct sets of experiments. In the first, he compared the velocity of transmission in the nerves of the laryngeal muscles (red voluntary muscles), and in those of the cervical position of the œsophagus (red involuntary muscles). In the second, the comparison was extended to the nerves of the terminal portion of the œsophagus (pale involuntary muscles). He finds that in the motor nerves of the red involuntary muscles, the velocity of transmission of centrifugal excitement is about eight times less than in the nerves of muscles which have an identical structure, but which belong to the portion of the muscular system that is controlled by the will.—*Comptes Rendus.* C.

**Production of Steel.**—Twenty years ago the production of steel, in the entire world, was little more than 300,000 tons, at an average cost of about $150 per ton. After the introduction of the modern processes of Bessemer (1860), Siemens-Martin (1868), and Pernot (1874), the production reached more than 2,200,000 tons in 1877, of which 1,800,000 tons were Bessemer metal, at an average price of $60 per ton. The remaining 400,000 tons were produced, chiefly, in reverberating furnaces, not in crucibles. The furnace steel, which in 1875 amounted to only 140,000 tons, reached 300,000 tons in 1877, and promises to increase still more rapidly than the Bessemer process

has done. These few figures may give some idea of the importance which the steel manufacture has assumed, since its substitution for iron, especially upon railways, has stimulated manufacturers to increase their facilities for its production.—*Il Politecnico.* C.

**Milk of the Cow Tree.**—Humboldt states that, among the great number of curious phenomena which he observed, there were few which impressed his imagination so vividly as that of a tree which yields an abundant supply of milk, resembling in its properties the milk of animals. This tree, *Brosimum galactodendron*, is found on the declivities of the Venezuelan mountains. The sap is thicker than cow's milk, and has a slightly acid reaction; when exposed to the air it sours, and deposits an abundant coagulum, a kind of cheese. Boussingault has lately subjected it to a chemical examination, and finds: 1. A fatty substance similar to beeswax, fusible at 50° (122° Fahr.), partly saponifiable, very soluble in ether, slightly soluble in boiling alcohol. This material acquires, after being melted and cooled, the appearance of virgin wax, and candles have been made of it. 2. A nitrogenous substance, resembling caseine in its fibrous structure, reminding one of the vegetable fibrine which Vauquelin has lately found in the sap of the *Carica papaya*. 3. Sugary substances. 4. Phosphates and other salts of potash, lime and magnesia. Boussingault closes his communication by the following comparison with an analysis of sweet cream, by M. Jeannier:

| | Vegetable milk. | Cream. |
|---|---|---|
| Saponifiable materials, . . | 35·2 | 34·3 |
| Sugary materials, . . . | 2 8 | 4·0 |
| Caseine and salts, . . . | 4·0 | 3·5 |
| Water, . . . . . | 58·0 | 58·2 |
| | 100·0 | 100·0 |

—*Comptes Rendus.* C.

**Acoustic Gallery at Bex.**—Prof. Ch. Dufour, during the last session of the Swedish Society of Natural Sciences at Bex, observed a remarkable echo in the church. The interior is of a rectangular form, with one end rounded. The pulpit is nearly in the middle of one of the large sides of the rectangle. Persons in front of the pulpit hear a speaker, at its foot and a little to the right, with great difficulty; but an auditor standing at two or three metres from the middle of the rounding part hears, with remarkable distinctness, the

slightest words which are spoken at the foot of the pulpit. Dufour considers this effect more remarkable than the one in the cupola of St. Paul's, at London, and than that in the halls of the Conservatoire des Arts et Metiers, at Paris.—*Bull. Soc. Baud.* C.

**Waters of the Danube and the Aach.**—A curious experiment has lately been made in order to decide a dispute between manufacturers, some of whom used the waters of the Danube and others that of the Aach, a tributary of Lake Constance. The distance which separates these two rivers is about 14 kilometres (8·7 miles), and the sources of the Aach are 150 metres (492·12 ft.) lower than the surface of the Danube; the latter runs over a calcareous bed having the same inclination as the line which would join the Danube to the sources of the Aach. As the bed of the Danube is cracked, and as it was noticed that that river lost a considerable part of its waters in this region, it was natural to suppose that the Aach was fed by the infiltration. The mill-owners upon the Danube, whose water failed in times of drought, wished to maintain the level, and sought to prevent the escape by filling up the crevices. The proprietors of the Aach objected to this on the ground of its interfering with their supply. It was, therefore, desirable to ascertain whether the supposed connection really existed. Prof. Knapp placed ten thousand kilogrammes (22,046 pounds) of salt in a cavity of the bed of the Danube. Analyses of the waters of the Aach, repeated at different intervals during a number of hours, showed that they contained an unusual proportion of salt. M. Tenbrink proposed to use the coloring power of fluorescine, which is so great that one part can be recognized in twenty million parts of water. On October 9th, 1877, at 5 P. M. about fifty litres (52·83 quarts) of a solution of fluorescine were poured into the Danube. On the 12th of October observers noticed that the waters of the Aach were colored. It had required 60 hours for these colored waters to traverse the intervening soil. The coloring increased during that day, from the morning till the evening, and was plainly visible until the following day at 3 P. M. Although this process can have few applications, it could be usefully employed in some special circumstances, and it is therefore proper that it should be placed upon record.—*Ann. des Ponts et Chauss.*

[The mean subterranean velocity of the colored water was only about 766 feet per hour. It seems probable, therefore, that there

were numerous caves, which must all be tinged by the flourescine before any traces of it could be seen in the Aach. In calcareous beds such caves are of frequent occurrence.] C.

**Adhesion of Laminated Metals.**—M. Felix Marquet applied to M. Tresca for advice as to the possibility of producing air-tight adhesion by simple pressure upon tin plates. He was referred to M. Thomaset, the inventor of a new hydraulic press, by means of which extraordinary pressure can be obtained. Finding that there was no adhesion, even after a pressure of many hundred atmospheres, Marquet used a stopping wire between the edges of the plates, and thus secured an air-tight joint as staunch as if they were soldered together. —*Les Mondes.* C.

**Platinum Plating.**—Great difficulties have been experienced in securing a platinum deposit of uniform color and sufficiently adhesive to secure copper and other metallic vessels from the corrosive action of acids. Böttger recommends a solution of freshly-precipitated, well-washed double chloride of platinum and ammonia in a tolerably strong boiling solution of citrate of soda. By using two strong Bunsen elements with such a solution, a beautiful, brilliant adhesive coating of pure platinum may be secured.—*Dingler's Jour.* C.

**Spectroscopic Temperatures.**—A. Crova has measured the calorific intensity of different portions of spectra, by means of a thermo-electric pile and a very sensitive galvanometer. Representing by 1000 the calorific intensity which corresponds to a red ray with a wave-length of 676 millionths of a millimetre, he gives the following table:

| | | | | | | |
|---|---|---|---|---|---|---|
| Wave-lengths, . | 676 | 605 | 560 | 523 | 486 | 459 |
| Sun-light, . . | 1000 | 820 | 760 | 670 | 540 | 460 |
| Electric-light, . | 1000 | 707 | 597 | 506 | 307 | 228 |
| Drummond-light, . | 1000 | 573 | 490 | 299 | 168 | 73 |
| Standard lamp, . | 1000 | 442 | 296 | 166 | 80 | 27 |

The electric-light was derived from 60 large Bunsen elements, with Carré's carbons, in the focus of a concave metallic mirror; the standard lamp was filled with colza oil. Crova concludes that temperatures can be rigidly determined by the spectrometric method, as soon as we have ascertained the exact law of emission for all the rays and the numerical constants for each wave-length. He presents these results as a first essay towards the solution of this important question.—*Comptes Rendus.* C.

**Safeguards against Boiler Explosions.**—In the Congress of Civil Engineers, at the Paris Exposition, Testud de Beauregard suggested the use of suitable thermometers or galvanometers to give timely warning of any dangerous disturbance of thermal equilibrium, whether between the boiler and the water or between the water and the steam. Even if the warning should not be given in time to prevent an explosion, it might be the means of saving the lives of engineers, operatives, bystanders or neighbors.—*La Gaceta Industrial.* C.

**Artificial Diamonds.**—The heirs of M. Gannal have found, among his papers, a memoir relative to the artificial preparation of diamonds by the reaction of phosphorus upon carbon sulphuret. The French Academy has placed the memoir in the hands of Vauquelin and Chevreul, for examination.—*Comptes Rendus.* C.

**Large Magnet.**—MM. Ducretet et Cie. exhibited, at the Paris Exhibition, a Faraday electro-magnet, which they claimed to be the most powerful that has ever been made. The coils have a diameter of 50 centimetres (19·7 inches), and a height of 60 cm. (23·6 inches). The total weight is 950 kilogrammes (2193·6 pounds). The helices are made up of numerous parallel and separately insulated wires, in order to facilitate different combinations, both in tension and in quantity.—*La Nature.* C.

**View from the Giffard Balloon.**—At the height of 150 or 200 metres (492 to 656 feet), the whole of Paris can be seen. By ascending 400 or 500 metres (1312 to 1640 feet), the great city, reduced to Liliputian proportions, appears in the centre of a vast circle of verdure, which comprises four "departements," and which has a diameter of 120 kilometres (74 566 miles).—*La Nature.*

**Telephonic Determination of the Magnetic Meridian.**—M. H. de Parville substitutes a bar of soft iron, at least 1 metre (39·37 inches) in length, for the short magnet of an ordinary telephone. The apparatus still transmits sounds, but with an intensity which varies with the direction of the bar, the sound being most intense in the receiver when the transmitter is parallel to the dipping needle. The sound is more or less completely extinguished when the transmitter is perpendicular to the magnetic meridian. If such a telephone is provided with a resonator, it can be used not only to find the direction of the magnetic needle, but also for the approxi-

mate determination of the variations in magnetic intensity. This method seems applicable, on ship-board, for the correction of the compass, especially when the indications of the needle may be deceptive, on account of the neighborhood of magnetic rocks, or of islands rich in iron ores. The inventor also suggests the use of a bar of soft iron, several metres in length, having, at one end, a magnetic coil with a self-registering apparatus. The pitching of the vessel would excite induction currents, and the diagram on the register would reveal the direction of the vessel, so as to check the indications of the compass.—*Comptes Rendus.* C.

**Comparative Wear of Iron and Steel Rails.**—Near Oberthausen, on the line from Cologne to Minden, a variety of rails were laid in 1864, and taken up in 1876. The traffic was very great, and the percentage of replacement in twelve years was as follows: Wrought iron rails, from the Frederich-Wilhelm works, 80·66; wrought iron, from Phœnix works, 68·00; puddled steel, of Funke & Co., 33·33; puddled steel, of Hosch & Sons, 33·33; Hosch & Sons' Bessemer, 4·70; Krupp's Bessemer, 4·08; Hörder-Verein Bessemer, 1·33.—*Annales Industr.* C.

**Composition of Ancient Glass.**—Peligot has lately been engaged upon various analyses of glass, and turned his attention especially towards some of the oldest specimens that he could find. There is considerable difference in the composition of modern glass in different districts, but all manufacturers agree in employing three materials, lime and silex being almost invariably used, with either potash or soda as a flux. The glass-makers of antiquity used only sand and an alkali, and this is one reason why their glass had so little durability. The credit of inventing flint glass, or the modern crystal, is due entirely to the English.—*Ann. de. Chem. et de Phys.* C.

**Harmonic Striæ.**—C. Decharme has studied the relation which exists between the breadth of the striæ, which are produced in a thin layer of water upon a vibrating circular plate, and the number of corresponding sound-vibrations. Photographing the net-work of nodes and internodes, and measuring the striæ, he finds that their breadths are inversely proportional to the square-roots of the numbers of vibrations in the corresponding sounds.—*Comptes Rendus.* C.

**A New Stone-Dressing Machine.**—*Der Maschinen Constructeur*, No. 18, gives a short description of a new tool for dressing stone, which is now on exhibition at Paris, built by Brunton and Trier, Batersea Foundry, London, England.

A large, hollow face-plate is bolted to a hollow spindle, which is rotated by means of a pulley fastened to the same. The face-plate carries, near its outer edge, a number of small disks, placed at an angle to the central axis, and which have a double motion—firstly, around the axis of the main spindle, and then around their own. The mechanism is arranged to let a point of the disk's sharp edge describe a curve of a cycloidal nature on the face of the stone. There is, consequently, but little friction, which is very evident to the observer, as no sparks are visible, even while operating on the hardest material. The disks retain their sharp edges for a considerable length of time, and do not even heat.

Through the hollow spindle runs a solid one, carrying a bevel gear-wheel, which is inside the face-plate, and does not rotate, as a rule, but gives motion, through separate bevel-pinions, to the disk-spindles, whose bearings are in the face-plate. When, however, the diameter of the disks has been reduced by grinding, so as to impair the cycloidal nature of the curve before mentioned, it is necessary to give the central wheel a slow motion, to correct the error. The whole can be fed to and fro in the direction of the axis, to regulate the depth of the cut.

The machine is provided with several tables, which, besides the ordinary sliding surfaces and rack for propulsion, also have wheels, allowing the tables to be changed, and the work to go on uninterruptedly.

The machine on exhibition can dress a surface 1·4 metres (4 ft. 7·1 in.) wide, the length depending only on the length of the table or bed. The face-plate makes 100 revolutions per minute, each of the 12 disks, 600. The diameter over the outside of the disks is 1·8 metres (5 ft. 10·9 in.).

Owing to the high rate of speed, the disks, 30 cm. (11·7 in.) in diameter, can be made of very hard, chilled cast iron.

An idea of the capacity of this machine, may be gained from the following data:

1 sq. metre = 10·77 sq. ft. of granite, was dressed in 4 minutes.
" " " hard limestone, " " 2½ "
" " " sandstone " " 2 "

A cut 3 to 4 cm. (1·2 in. to 1·6 in.) deep, can be taken. P.

**Cobalt in Electro-Metallurgy.**—In studying some of the properties of magnetic metals obtained by means of galvanism, the attention of M. Gaiffe was attracted by the beauty of cobalt, and its hardness, which is much superior to that of iron and nickel; and the thought struck him that it might be possible to utilize this metal under certain circumstances, should it be found as easy to deposit it by the battery as it is the metals just mentioned.

It is well suited, for instance, to take the place of iron and nickel as a protective coating for plates used in copper-plate engraving. It does not oxidize like iron, and demands but little care for its preservation; it is dissolved with the greatest ease by weak acids which do not attack the copper, while nickel deposited on a copper plate cannot be renewed without injury to the latter. Its beautiful color will also cause it to be used for the decoration of other metals. The bath with which M. Gaiffe obtained very beautiful specimens was a neutral solution of double sulphate of cobalt and ammonia, which requires for its preparation scarcely as much care as baths of nickel. The anode may be a sheet of platinum, or, better yet, a plate of cobalt, either cast or forged. In this, cobalt differs from iron and nickel, which are soluble in thin baths only when they are in contact or combination with a body that is electro-negative with respect to them. In order to obtain a white, adherent deposit, the electric current should be regulated in the beginning at 6 volts, and should be reduced to 3 volts when the whole surface of the piece to be covered has become white. With a proper intensity of current, the deposit of cobalt takes place almost as rapidly as that of nickel. In four hours a layer of cobalt 0·025 millimetre thick may be obtained. When it is desired to obtain a very regular deposit, it is indispensable to fix the object to be "cobalted" to the electrode of the battery before immersing it in the bath. Without this precaution there would be produced an appearance of marbling, only removable by recommencing the process.—*Scientific American.*

**Transmission of Minute Sound-Waves by the Telephone.**—In the course of some experiments on a telephone line, with a view to decrease the crackling due to atmospheric disturbance, an observation was made by Prof. Frazer, which will serve to illustrate to what an infinitesimal motion the sounds heard through the telephone are sometimes due. A telephone was selected, in which the diaphragm was held fast along a circular rim, instead of the flat surface, which usually binds the outside of metal plate. It was found to resound to one note (middle A of piano).

On sounding this note clearly into the mouth-piece, while keeping the other telephones covered, so as not to be directly affected by the air-waves, it was found that the overtones, so very manifest in the vibrations of such metal disks, were distinctly traceable in the other telephones, with which connection was had over a line of about one-third of a mile, with a ground return-circuit.

It is difficult to understand that the minute waves into which a metal plate is thrown by a vigorous note of the voice, can reproduce sound through the intermediate agency of maxima and minima of conductivity, in the medium of current transmission; but that the minute wavelets which are produced upon the backs of these, should each result in fluctuations of conductivity of sufficient power to impress themselves as sounds at the extremity of a long line, could scarcely have been foreseen. The experiment was only tried with the telephones in the same room, and has not yet been verified by distinguishing the overtones in the more remote instruments.

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## ANOTHER VERIFICATION OF PREDICTION.

The following note was received since Prof. Chase's article on "Astronomical Forecasts," page 314, was printed.—Eds. J. F. I.

HAVERFORD COLLEGE, *Oct.* 26, 1878.

*Editors* JOURNAL FRANKLIN INSTITUTE:

*Gentlemen*,—Gaillot's computed orbit for Watson's second intra-Mercurial planet represents another term of my harmonic series:

| | |
|---|---|
| Gaillot (*Comptes Rendus*, Sept. 30), . . | ·1803 |
| Chase ($\frac{1}{19}$ node of Jupiter-subsidence), . . | ·1826 |

Yours, truly, PLINY E. CHASE.

# Book Notices.

AN ELEMENTARY COURSE OF CIVIL ENGINEERING. By J. B. Wheeler, Professor of Civil and Military Engineering, U. S. Military Academy. 8vo, pp. 472. J. Wiley & Sons, N. Y.

It is impossible to include within the compass of one volume of four or five hundred pages, a satisfactory elementary review of the various subdivisions of civil engineering, as practiced at the present day.

Professor Wheeler has doubtless been impelled to make the attempt by the necessities of his scholars, and the limited time allotted to pure civil engineering at West Point, and has given to the public a very ably compiled volume.

The reader of this work, however, gets but a glimpse of the vast field of industry which lies before him in each subdivision, and the usefulness of the work would be increased very greatly, by careful references to the various sources from which the information here given has been derived, thus enabling the reader to follow the clue given by a short reference, and obtain a thorough knowledge of whatever department of engineering he may, for any reason, be desirous of knowing more.

Part I, on building materials, is as concisely and thoroughly treated as the limits of the book will permit; it is, however, a department of engineering in which knowledge comes rather from experience and close observation than from much reading.

Part II, on the strength of materials, is based rather on empirical formulæ, than on the more modern German methods, which are equally correct and have the advantage of being logically deduced, and therefore more easily remembered, or deduced, by the student.

It is to be regretted that in the parts on framing, trussed bridges, and roofs, the applications of the newer, simpler and sufficiently correct methods of graphical statics, have not to a greater extent taken the place of the older and more involved analytical methods. Once learned, the graphical methods are never forgotten.

The space allotted to Railroads is too limited to do more than merely notice a few points in this vast field, and, strangely enough, some points of very little or no importance are quite as fully noticed as the more salient and important ones.

In Roads and Canals the work does not differ greatly from the older work of Mahan, for the very good reason that but few improvements have been made in the construction of either, since the publication of Mahan's Civil Engineering, which has served as a model for this work.

M.

BAGGAGE CAR TRAFFIC. By Marshall M. Kirkman. Small 8vo, pp. 238. New York, *Railroad Gazette*, 1878.

No more striking proof of the intricacy involved in latter-day railway management could be adduced, than this book of 250 pages on what might seem a comparatively unimportant subject—the baggage car traffic on passenger trains.

The work is an exhaustive treatise, written in popular style, on the American system of handling baggage; the advantages of which were so strikingly exemplified during the Centennial; and also a comparison with foreign methods of doing the same work; and, strange as it may seem to the American railroader, a hint or two may be taken from our transatlantic cousins, upon whom the curse of hurry has not fallen so heavily as on us.

There is wit as well as wisdom in the book; witness the pen portraits of the train-boy and baggage-master, which much maligned individual is vindicated at the author's hands.

That no "'prentice hand" or theorizing amateur is writing, is proved by the absence of those ludicrous blunders so often perceived by experts in works of this class.

In short, it would pay every Railroad Company to buy a few copies of the book, and pass them around among its baggage-masters, who would gladly read what any one might have to say about their department, for among no body of men, outside of the army and navy, is the *esprit du corps* stronger than among railroad employees, and none are more jealous of their reputation for smartness in their own line. R.

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THE ROADMASTER'S ASSISTANT AND SECTION-MASTER'S GUIDE. By Wm. S. Huntington. Small 8vo. New York, *Railroad Gazette*, 1878.

This is a book for which there has been a real need, since it is high time for the experience of practical railroad men in every department to be recorded for the benefit of their successors.

To one who has had opportunity of seeing the manner in which the permanent way of many of our railroads is maintained, and the class of men to whom the work is intrusted, it almost seems as though accidents should be the rule, instead of the exception.

Although the permanent way and works of many of our trunk lines and their connections have been brought to a high standard of perfection, these form but a small part of our great railway mileage.

Very many of the railroads in this country are struggling to make both ends meet and to pay fixed charges, compelled by competition to run heavy trains at high speeds, and with but little money with which to repair the destruction of tracks and bridges which they

cause; and it is to the roadmasters and foremen of such railroads that this book will be particularly useful, since it shows them that it costs no more to do work right than wrong.

The chapters on Track-laying and Track-repairs are particularly full of detail, and are, of course, the more valuable on that account; the cuts are clear, but there might be more of them.

The one great omission in this book is the lack of information regarding the nature, mode of handling, and manner of laying steel rails, which now form so important a part of railway economy.

The "sighting in" of ties, a method of doing which is described, has been very generally abandoned in the east, the ties being thrown down on the road-bed as left by the contractor, the rails being spiked at, and opposite, the joints, and then the whole track brought to surface and full-spiked, care being exercised lest the rails be bent or twisted by the material train.

The tables of elevations for outer rail of curves, and the bills of switch timbers, will be useful for reference; the index (so important in a work of this description) is all that can be desired, and the information generally is conveyed in so simple a style, that any man who can read at all should be able to understand it, which is the more necessary, as railroad foremen are not apt to be men of letters.

R.

## LECTURES AT THE FRANKLIN INSTITUTE.

The lecture season for 1878–9 will begin on November 7th, 1878, and continue on Monday and Thursday evenings until February 24th, 1879.

The Institute now having increased facilities for illustrating the useful application of science, a larger number of lectures upon such subjects have been provided for, and among these are several which are now attracting a large amount of popular attention.

The gentlemen whose services have been secured for this season, and the subjects selected, are as follows:

Prof. E. J. Houston, on Thursdays, beginning November 7th, 1878. Six lectures, on *Color*, *Lightning Rods*, *Electro-Magnetism*, *Telephone and Microphone*, *Relations of Light and Heat*, and *Conservation of Energy*.

Dr. Wm. H. Greene, on Mondays, beginning November 11th, 1878. Eight lectures, on Organic Chemistry, or the *Chemistry of Carbon Compounds*.

Prof. Elihu Thomson, on Thursdays, beginning January 2d, 1879. Five lectures, on *Explosive Compounds*, *Mirrors and Lenses*, *The Spectroscope*, *Electric Lighting*, and *Electro-Chemistry*.

Prof. Persifor Frazer, Jr., on Mondays, beginning January 6th, 1879. *An Introduction to Modern Chemistry and Physics*, in eight lectures.

Mr. J. B. Knight, on Thursday, February 6th, 1879. One lecture, on *Ice*.

Mr. D. S. Holman, on Thursdays, February 13th and 20th, 1879. Two lectures on *Motion and Life*, and *The Movement of Fluids in Plants and Animals, as seen with the Microscope*.

## Franklin Institute.

Hall of the Institute, Oct. 16th, 1878.

The stated meeting was called to order at 8 o'clock P. M., Vice-President J. E. Mitchel in the chair.

There were present 104 members and 30 visitors.

The minutes of the last meeting were read and approved.

The Actuary presented the minutes of the Board of Managers, and reported that at the last meeting there were 5 persons elected members of the Institute, and the following donations made to the Library:

Geological report of Chesapeake and Ohio Railroad. By T. S. Ridgway.

Chesapeake and Ohio Railroad. Its advantages, etc., etc.

Letter of Prof. E. B. Andrews, on the Coal and Iron deposits in Perry county, Ohio.

Coal and Iron fields of Virginia and West Virginia. By D. T. Ansted.

Maps Nos. 6, 7, 9 and 10 of Grouped sections of Galla, Meigs, Morgan and Muskingum counties. By Andrews & Gilbert.

From C. H. Brownings, New York.

Maps (26) of Operations of the Union and Confederate Armies during 1863, '64 and '65.

Supplement to Official Gazette of United States Patent Office.

Specifications and Drawings of United States Patents for March 1878. From the Patent Office, Washington.

Geological Survey of Pennsylvania, 1875–1877. Reports of progress. 3 K. N.; & Q.

From the Board of Commissioners, Harrisburg.

Annual Report of Light-House Board for year ending June 30, 1877. From the Secretary of the Treasury, Washington.

New View of the Weather Question. By J. P. Noyes. From the Author.

Bearing Piles. Compiled by R. Herring. From the Author.

Resistance des Materiaux. Par A. Morin. From the Author.

Electricity in Medicine and Surgery. From Western Electric Manufacturing Co.

Uniform Non-Local Time. A Memoir. By I. Fleming. From the Author.

Report on Widening of Delaware Avenue. From Clerk of Councils.

On a Dynamometer for Measuring Steam and Water-power.

Report on the Meteor of December 24th, 1873.

Report on the Metric System of Weights and Measures. April, 1878. From Engineers' Club of Philadelphia.

Alabama Coal and Navigation Company. Charter, August 22, 1871. From the Company.

Letter on the Tariff Question. By B. H. Moore. Philadelphia, 1878. From the Author.

Report to Board of Underwriters of New York. By C. H. Haswell, N. Y., 1877. From the Author.

Catalogues of the Central University. Richmond, Ky., 1876–77 and 1877–78. From the University.

Forty-second annual report of Directors of Ohio Mechanics' Institute. Cincinnati, 1870. From the Institute.

Eighteenth report to Council of City of Manchester on the working of the Public Free Library. 1869–70. From the Council.

Rules of Practice in the United States Patent Office. February and August, 1878. From E. Hiltebrand.

Harbor Bars. The Cause of their Formation. By H. F. Knapp. London, 1878. From the Author.

Report on Ventilation of Hall of Representatives. By R. Briggs, 1876. From the Author.

Eighth and Ninth reports upon the Improvement of the South Pass of the Mississippi River. By M. R. Brown. 1877 and 1878. From the Chief of Engineers, Washington.

Obituary Notice of J. C. Cresson. By F. Fraley. From the Author.

Annual report of Chief Engineer of Water Department of Wilmington, for 1877. From the Chief Engineer.

Iron and Steel Tests. By R. H. Thurston. From the Author.

Addenda to the report of Health Officer of Philadelphia, for 1877. From Health Officer.

Eighth report of President and Directors of the Lake Shore and Michigan Southern Railway Co., for 1877. From the Company.

Researches in Graphical Statistics. By Henry T. Eddy. New York, 1878. From the Author.

Fifty-eighth annual report of Managers of Apprentices' Library Company of Philadelphia. 1878. From the Company.

American Printer. By Thos. MacKellar. Philadelphia, 1878. From the Author.

Catalogue of Venezuelan Department at International Exhibition, 1876. From L. De la Cova, Consul for Venezuela, Philada.

Report on the Incrustation in Boilers. By Dr. R. Smith.

Report of Committee on Management of the Manchester Steam Users' Association. 1857, 1859, 1862 and 1877.

Report of Proceedings at Sixth annual meeting, held January 15, 1861.

Chief Engineer's annual report on the Periodical Indication and Inspection of Engines. 1877.

From Manchester Steam Users' Asso., Manchester, England.

The Secretary presented and described John G. Baker's Improvement in Drawing Boards, consisting of a metal ruler to be used in place of the ordinary T-square. This ruler is of the full length of the board, and carries a shaft supported by short studs on its upper face. At each end of the shaft are pinions, gearing into racks fastened to the ends of the board, thus ensuring parallelism in the movement of the ruler.

Also, Crook's Condenser, for steam engines, consisting of a nozzle inserted in the exhaust-pipe, and of such shape that when water is admitted, it is spread out in a thin sheet diagonally across the exhaust-pipe, thus facilitating the contact between the water and steam.

Mr. Howard Murphy described, and illustrated by means of the electric light, a simple photographic process for reproducing drawings. A strong, hard paper, such as ledger paper, is coated lightly by means of a camel's hair brush, with a sensitive solution, consisting of 1 part citrate of iron and ammonia, 1 part red prussiate of